A

TREATISE ON GEOLOGY,

BY

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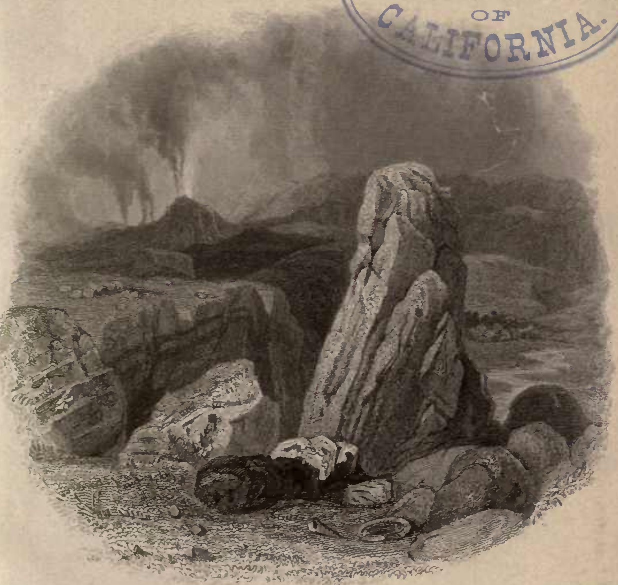
VOL. II.



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A

TREATISE ON GEOLOGY.

CHAPTER VI.—*continued.*

FLUVIATILE AND LACUSTRINE DEPOSITS.

We now quit the marine deposits of tertiary and post-tertiary age, and fix our attention on a parallel series of accumulations, in valleys, and ancient lakes, for the most part under the influence of fresh waters. In treating of formations in valleys, we cannot always confine our illustrations to the operations of fresh waters, because continued research appears, in several instances, to show that what appeared at first to be due to lacustrine fluctuation or river currents was really the effect of water-movement in an ancient arm of the sea. This result is quite to be expected. Valleys have been the channels of strong sea currents before they were raised above the ocean and filled with precipitations from the air: valleys were subaqueous before they became subaërial, and in them we ought to find marks of marine followed by other marks of fluviatile action.

When shells are absent (as they most frequently are), we may not always be able to distinguish between the beaches left by the retiring sea and the banks left by rapid inundations formerly flowing at higher levels.

No uncertainty of this kind is felt in tracing the history of the purely lacustrine deposits: for these seldom are deficient in the characteristic organic forms of fresh water. Perhaps in both of these classes of phenomena, we may reasonably look for more zealous and persevering research than have been lately bestowed upon them. Old lakes deserve all the attention of palæontology and physical geology: for their history goes far back on the scale of geological time, and by their contents we know at least somewhat of our "native" land in pleistocene, tertiary, oolitic, and perhaps carboniferous periods. Nor is any survey of the primeval world at all complete which fails to inquire into the river action of early geological times, since this action is an index of the state of the land, and many of our valleys are even of palæozoic date, and contain conglomerates heaped in them by palæozoic, mesozoic, and cainozoic waves. And, even where no trace of the valley remains, we not unfrequently mark the positive effect, or the probable vicinity, of a great ancient river. Thus, in the Weald of Sussex, we have such a combination of reliquiæ as to mark, not a bay of the sea, but an estuary nourished by a richly wooded river; nor can we easily escape from the conviction that the alternating sediments of the coal formation in many cases require the intervention of powerful streams from the land. To show where that land was posited, and what was its character, may be an impracticable problem, but it cannot be prosecuted without some indirect advantages, perhaps more than commensurate with the effort which it requires.

The recent work of Mr. Chambers, entitled "Ancient Sea Margins," may be perused with advantage for many examples of old sea and tide river terraces at various stated levels, round a great part of the British shores, and along many of the valleys.

Ancient Valley Formations.

I have some time ago proposed this term, for the purpose of combining in one point of view a great number of remarkable ancient phenomena, attesting the former action of water *in existing valleys*, but flowing at higher levels than the actual stream, unless the land has been raised and sunk. Deposits of gravel at the mouth of a valley, in the form of terraces, abound in most mountain countries (*e. g.* foot of Glen Roy), on the sides of a valley (as in Tynedale, above Newcastle), at the head of a valley (as at the head of several Cumberland glens).

In Glen Roy, at a very high level, are two parallel lines, or terraces, which run round the mountain sides, and communicate with other drainage streams. The deposit called Lõss, on the Rhine, appears of the same nature, so far, at least, as to indicate the deposition of sediments in water flowing at a level many hundred feet above the present River Rhine, and extending beyond what is now its proper valley on the north side of the range of the Ardennes.*

In some of these cases there is sufficient proof that the water was not marine, land shells being not unfrequently found in the deposits, especially the finer sorts of sediments. The level character of the terraces, which is the most usual form of these accumulations, seems to indicate the existence of ancient lakes at a high level in the valleys where they occur.

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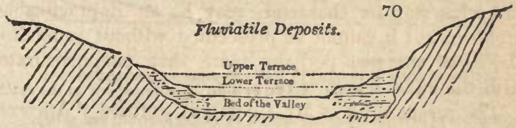
Fluviatile Deposits.



This, however, is less certain than may be commonly imagined; for streams like the rough Arve scatter the detritus brought down from the glaciers over a surface gently declining, as the stream runs, but nearly level in the transverse section. If, by any change of the

* Lyell, in Geol. Proc.

physical conditions, the stream should cut its way to a greater depth, the banks would have that terrace form which belongs to the Lune, the Ouse, the Tees, the Tyne, and many rivers of the North of England. It not uncommonly happens, that two such terraces, at different levels, can be traced for some distance on the sides of a valley, as on the Lune;—occasionally, in the midst of a valley, rises a low hill of gravel corresponding to the lateral terraces. In most valleys, the materials of the terraces are such as the rocks on the sides of the mountains yield; but this is not the case on the Lune about Kirkby Lonsdale, or the Tyne above Newcastle, in both of which situations boulders and gravel from the Cumbrian mountains constitute a considerable part of the deposit. For this reason, they would probably be called diluvial deposits by some writers, and described as raised breaches by others. The confused aggregation of the pebbles, sand, &c. is such as to imply sudden and violent inundations, which delivered a vast body of detritus in a short time, and perhaps followed the line of the valley, but deposited the coarse earthy matters near the sides where the velocity was lessened, as powerful streams are always found to do.

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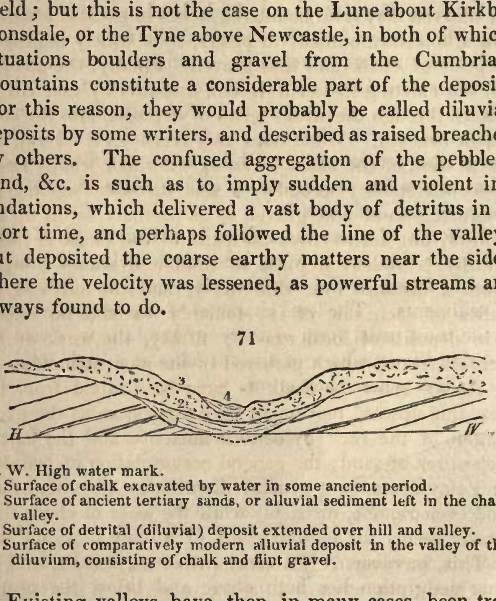

H. W. High water mark.
1. Surface of chalk excavated by water in some ancient period.
2. Surface of ancient tertiary sands, or alluvial sediment left in the chalk valley.
3. Surface of detrital (diluvial) deposit extended over hill and valley.
4. Surface of comparatively modern alluvial deposit in the valley of the diluvium, consisting of chalk and flint gravel.

Existing valleys have, then, in many cases, been traversed by floods of water which have left evidence of their volume, force, and direction. Did they excavate the valleys? or merely follow the traces left by earlier watery violence? Perhaps we must not yet venture to propose a general answer to such questions; — there exist, however, cases which bear very decided evidence with reference to them. At a little valley in the chalk of Yorkshire (represented in the diagram, page 4.), which opens to the sea near Bridlington, we behold, as in the above sketch, the solid, laminated chalk, gently declining to the south, excavated in a broad undulation across the laminæ; over nearly the whole breadth of the hollow thus occasioned rests an irregular sandy deposit very much of tertiary aspect; above this, a thick mass of diluvial clay with bouldered stones in great confusion; the whole surmounted, in places, by a widely laminated deposit of chalk and flint gravel. Finally, the channel of the existing little rill is cut, certainly by that rill, in places through the whole series of deposits, into the solid chalk beneath. What does this teach us? First, the excavation of the chalk by an agent which wholly swept away the spoils; secondly, a less turbulent agency introducing sand and gravel, so as partially to fill up the hollow, but not to cover the parts of the chalk beyond; thirdly, a violent impulse of mud and stones brought from a distance over this valley, and the surfaces for miles on each side of it; fourthly, variable but extensive deposits of local gravel; fifthly, the work of the actual stream, which gathered in the ancient hollow.

As we know the chalk to have been raised from the sea, this upward movement may suggest to us the excavation of the rock by oceanic currents, and the partial deposition of sand; the general accumulation of boulders and clay demands a general disturbance affecting other, and even remote, districts; while the mass of chalk flint gravel seems the natural effect of a more local and less violent convulsion. In some instances, local gravel of this description lies both above and below the proper diluvium.

The interval of time here supposed to occur between the original excavation of a hollow or valley in the rocks, and the accumulation in it of the spoils of a violent commotion of water, is indeterminate. So, indeed, is that between the cessation of the diluvial floods (whatever they were) and the commencement of the actual stream. Judging from a survey of examples in the North of England, we have no doubt that many of these old river terraces are the remains of estuary deltas accumulated when the sea had wider dominion ; and we are strongly impressed with the conviction that it is possible now to point out in certain sheltered spots the pebbly shores which, like the modern Spurn, formed the seaward barrier of these estuaries.

Rock Terraces in Valleys. — There is a peculiar class of terraces in valleys, which indicate in the same manner the successive lowering of the level of descending water (or the successive rising of the land); these terraces are formed by solid rock, with little or no trace of gravel, or other detritus. Such cases are frequent in the mining dales of the North of England, which cut deep into the "Yoredale Rocks," or upper mountain limestone series.*

In this varied series of limestone, sandstone, and shale, almost every limestone which overlies shale projects into a terrace; and this sometimes happens to strong sandstones similarly circumstanced. It is easy to see that, as this occurs in many of the branching lesser dales, as well as in the principal valley, it may plausibly be argued that the whole effect is due to atmospheric action. It is probable, however, that this is not a sufficient cause ; since additional débris might thus be expected to be falling every day, or, at least, more of this accumulation should remain than we see. We must further observe, that the presumed levels of the water are only clearly marked by continuous terraces when the strata dip nearly in the plane of the valley. It appears, that just as, at this day, a mountain stream crossing the Yoredale Rocks forms waterfalls and cliffs at every ledge of limestone, by the wearing away of the subjacent shales — so the great currents which anciently flowed in the valley

* Geol. of Yorkshire, vol. ii.

(whatever they were) excavated the softer strata, and left the hard prominent in terrace cliffs, as in diag. No. 72.

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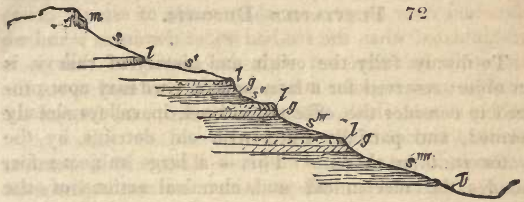
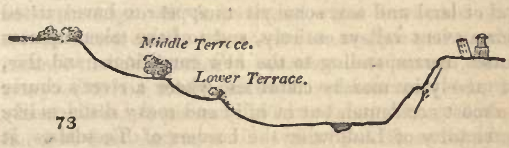


m. Millstone grit summit resting on shales and grits to *l*, which is limestone, and projects over *s*, the subjacent argillaceous beds. The same occurs with each lower ledge of limestone *l*, which, with the gritstone *g*, *usually* found beneath, forms a terrace on the hill sides, above a slope of shale.

A different case occurs in valleys which cross and enter deeply into thick masses of red sandstone, such as occurs at Nottingham, Kidderminster, Bridgnorth, &c. At Bridgnorth, for example, occurs a remarkable triple row of terraces on the east bank of the Severn, which appear decisive as to the successive operations by which changes of relative level of the land and the water which excavated the valley were brought about.

All the terraces represented in the diagram No. 73.



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are formed on the face of the thick and easily excavated red sandstone; but it is only on the left (east) bank of the Severn that they are conspicuous, because this is the salient angle, — for it is always observed among the common daily effects of inundations, that such terrace-like levels are only marked on the projecting land, while the re-entering angle is excavated to vertical or steep faces.

Fluviatile Deposits.

To discuss fully the origin and history of valleys, is an object reserved for a later section; we may now proceed to consider the effects produced, in valleys already formed, and partially filled with old detritus, by the water running therein. This is a large subject; for, besides the mechanical and chemical actions of the rivers and brooks, which vary according to the hardness and nature of the rocks, there is to be examined the influence of atmospheric vicissitudes, heat and cold, moisture, dryness, frost, &c.; and all the complicated effects thus occasioned are, in relation to the valleys, further modified by the form and slope of the urfaces, the occurrence of lakes, and other circumstances. Streams flowing along a valley under the various conditions which we observe, are to be considered both as eroding and transporting agents; and it is not only conceivable from the admitted instability of the level of land and sea, but perfectly demonstrated by observation, that these seemingly opposite effects have been exhibited at different times by the same river, at the same points of a valley. Moreover, in the course of the changes of level of land and sea, some rivers appear to have quitted their ancient valleys entirely, and to have taken up new courses corresponding to the new conditions; and this, not merely in marshy countries, where a river's course is almost accidental, but in hilly and rocky districts like the vicinity of Ludlow or the borders of Teesdale. It will, therefore, be proper to present as full an account of the phenomena relating to the actual configuration of valleys under different circumstances, as a due regard to reasonable limits will allow. The first thing to be considered is the degree in which the earth's surface is wasted by atmospheric changes and aqueous agency.

Waste of the Earth's Surface.

If we consider that the aggregation of rocks and minerals, whether we regard it as a fruit of chemical or mechanical actions, is no otherwise fixed or stable, than as the forces which tend to keep them united are superior to those which from all sides strive to separate them, we shall be prepared to comprehend how the *variations* of these constringent and divellent forces, according to heat, moisture, new elementary combinations, &c., bring a silent but sure and often rapid decay on all the structures of man, and on all the mightier monuments of nature, which are exposed to the ever-changing atmosphere. It is painful to mark the injuries effected by a few centuries on the richly sculptured arches of the Normans, the graceful mouldings of the early English architects, and the rich foliage of the decorated and later Gothic styles. The changing temperature and moisture of the air, communicated to the slowly conducting stone, especially on the western and southern fronts of buildings, bursts the parts near the surface into powder, or, by introducing a new arrangement of the particles, separates the external from the internal parts, and causes the exfoliation or desquamation, as Macculloch calls it, of whole sheets of stone parallel to the ornamental work of the mason. From these attacks, no shelter can wholly protect; the parts of a building which are below a ledge, often decay the first; oiling and painting will only retard the destruction; and stones which resist all watery agency, and refuse to burst with changes of temperature, are secretly eaten away by the chemical forces of carbonic acid and other atmospheric influences. What is thought to be more durable than granite? Yet this rock is rapidly consumed by the decomposition of its felspar, effected by carbonic acid gas, — a process which is sometimes conspicuous even in Britain (Arran, Muncaster Fell, Cumberland), but is rapidly performed in Auvergne, where carbonic acid gas issues plentifully from the volcanic regions.

Effects of Rain.

Mere rain is a powerful agent of disintegration; and its frequent attacks leave at length, in sandstones and limestones, otherwise very durable, channels of considerable dimensions, which have sometimes been ascribed to other causes. The Devil's Arrows at Boroughbridge, in Yorkshire, are fluted from this cause from top to bottom (except on the underhanging sides, where they cease not far below the summit) — the work of two or three thousand years: and when we turn from these monuments of man to the native crags whence they were cut, "Brinham rocks," and regard the awful waste and ruin there, well marked by the pinnacles and rocking stones which remain in picturesque desolation, it is difficult to avoid indulging a long train of reflection on the processes of decay and renovation which thus seem to visit even the inanimate kingdoms of nature, subjecting all its material elements to continually renewed combinations.

On the broad limestone floors which support the noble mountains of Ingleborough, Penyghent, and Whernside, the rain channels are so abundant as to have attracted the attention of artists and tourists; and on Hutton roof crags, as well as among the limestones of the Alps, they change their direction with the slope of the ground, collect into larger furrows like valleys on a broad surface, and terminate in the large deep fissures, as small valleys often end in a great hollow of drainage. Another remarkable phenomenon of the moorland districts of the North of England, which are formed on the Yoredale series of mountain limestone, may perhaps admit of the same explanation. These are the "Swallow" holes, as they are termed, which range above the outcrop edge of the limestone beds, and act as drainage channels from the surface to the jointed calcareous rocks below. These round or irregular pits and holes are smoothed on the faces and joints of stone, as if by the action of acidulated water, the origin of which, from the air or the neighbouring vegetable substances, is not hypothetical.

Effects of Frost.

In no form is the moisture of the atmosphere inefficient in accelerating the disintegration of rocks. Collected in the joints and cavities of mountains, it loosens every thing by its expansion and relaxation; heaped into enormous glaciers on the summits and down the valleys of the Alps, it melts at its lower edges and on the lower surfaces, and thus is ever in motion downwards; augmented from above and diminished from below, its moving masses plough up the solid earth, and, by a wonderful and momentarily insensible energy, pile up, on each side of the icy valley, vast quantities of blocks of stone and heaps of earth, which slowly advance into the lower ground; and these sometimes bear trees and admit cultivation; till, in the course of changes which these rude climates experience, the whole is transported away by the river which flows beneath, and space is left for new augmentations from above. Perhaps no circumstances are so favourable to the collection of materials for rivers to sweep away, as the glacial crown and icy valleys of the Alps, accompanied by the thundering avalanche and frequent landslips, like those of the Rossberg and the Righi. What further happens to these materials belongs to the history of the river.

In modern geological theory, the glacier has become a *power* not less influential than in other days the diluvial wave; but it is a power in daily action, of which the laws are known and the effects measurable. If, in applying this power to earlier phenomena, we employ larger measures than nature now works by, or stretch our lines in directions where glaciers are now unknown, we are always amenable to the ascertained laws of glacial action. If we may now venture to say these laws are *known*, let geology gratefully own her obligation to the cultivators of physical science, who following the adventurous steps of Saussure, Charpentier, and Agassiz, have, with Mallet, Darwin, Martins, Forbes, and Hopkins, measured, calculated, and imitated the glaciers of many mountains and various latitudes.

Snow is the parent of glaciers; mountains are only their birth-place. Mountain ranges may by their mere narrowness and steepness furnish no cradle; they may be in so dry a region that snows are not abundant, and glaciers grow but feebly, or have such very gradual slopes as to allow of only very slow downward movement. But where the climate favours abundant precipitation of aqueous vapour, on an expanse of high land amidst loftier peaks, from which steep valleys lead down to levels much below the snow-line, the glacier, fed by a perpetual growth from above, and wasted by an eternal corrosion at the lower extremity, is modified by continual transformations of interior substance, and stimulated by a never-ceasing activity of descent.

It is, in fact, a river of ice, slowly winding its way from an inexhaustible upper sea (*mer de glace*), losing at every instant a part of its substance, and undergoing change in all its features, till, bent, broken, and dissolved, it gives birth to a stormy river, or floats away in icebergs to cool far-distant seas.

The substance of a glacier is not snow, nor is it wholly pure ice; it consists of the peculiar icy compounds, and manifests the peculiar structures which are generated when snow, after partial and interrupted fusion, is re-aggregated by frost. If this fusion be complete, pure ice is the refrigerated result, and this appears in glaciers; but the greater part of the glacial mass is derived from *nevé*, which is the partially fused and re-aggregated snow. Such being its composition, its parts are not incoherent as snow, nor liquid as water, nor wholly incapable of mutual displacement as solid ice: but it has something of all these properties; for it moves in a coherent mass, which is capable of flexure and compression, but when overstrained breaks into fissures, and when overpressed is easily crushed. A mass with such a constitution, placed so as to glide down the inclined but very unequal channel of an Alpine valley, may well be expected to present singular phenomena; but these phenomena have not become really known except after long and patient scrutiny by most excellent observers. Saussure has rightly conceived the descent of glaciers to be due essentially to the downward solicitation of gravity; Forbes has measured this descent in different levels of the glacial stream, at different points on its surface, at the same level, at different depths, and in valleys of different characters: Hopkins has made experiments at home, which throw great light on the interrupted or gradual descent of the icy currents. Without pretending to analyse the innumerable memoirs on glacial movement and its geological effects *, we may endeavour to sketch the course of a glacier.

Glaciers do not begin to flow from the loftiest peaks of mountains which rise above the perpetual snow-line: there the only downward movement of the snow is by the "*avalanche*." But in the zone of variable temperature, where the summer melts the surface of the snows which winter had collected, the snowy mass becomes first bathed with water, and afterwards more or less consolidated by frost; it becomes in fact *nevé*, and, pressed downwards by gravity, begins to glide on its bed, or on surfaces of separation formed within itself, more or less parallel to the local slope of the valley. As we descend below the limit of perpetual snow, the ground, growing warmer, maintains fluidity below the glacier †, the descent of which thus becomes less impeded. The glacier moves faster in summer than in

* Saussure, Voyages dans les Alpes; Agassiz, Etudes sur les Glaciers; Forbes, Travels in the Alps, and Phil. Trans; Mallet, Proc. of Dublin Geol. Soc.; Hopkins, Phil. Magazine, Camb. Phil. Trans., may be specially cited in regard to glacial movement. De la Beche has collected a body of information in his Geological Observer.

† The glacier of the Aar was found by Agassiz to fill a valley 780 feet deep.

winter, faster in a warm day than in a cold night, faster in some seasons than in others. Its motion is continual though unequal; faster in the middle than at the sides, and at the surface than in the deeper parts.

The daily motion at a point of the side of the glacier of Montanvert was found by Forbes to be 17·5 inches; and at the centre 27·1: the general proportion of the central to the lateral movement being 1375 to 1000.

In one year the average descent of the Mer de glace was found to be 563 feet. The velocities vary in different parts of the glacier. In the upper part of the glacier above Montanvert 674 feet in a year: lower down 479: at the "Angle," 770: and below Montanvert, 1000.

While thus moving downward, the glacier is subject to enormous waste by the action of sun and wind.

The waste of the glacier above Montanvert is thus given by Forbes:—

1842.	ft.	ins.	Daily Rate.
June 26 to June 30,	1	9	4·1 inches.
July 28,	10	11	3·6
Aug. 9,	14	10	3·7
Sept. 16,	24	6·5	2·5

Thus only a small portion of the mass which quitted the snowy wilds at its source is found to reach the source of the Arve, which, indeed, is formed by a portion of that waste, which is thus indicated.

In the uppermost parts of the glacier some alternations appear of the more snowy and more icy parts of the mass; a kind of stratification. Farther down a peculiar structure, first distinctly described and explained by Professor J. Forbes, appears. This is the veined or ribboned structure, in which laminæ of blue compact ice alternate with other laminæ of ice full of air bubbles, placed in a vertical direction across the glacier. Lower down these plates are no longer vertical, but *dip* toward the source of the glacier; and they are no longer plane, but curved, so as to present a concavity toward the same point. "These alternate bands have all the appearance of being due to the formation of fissures in the aërated ice or consolidated *nevé*, which fissures, having been filled with water drained from the glacier and frozen during winter, have produced the compact blue bands."

The farther down the glacier we pass the more numerous are the fissures, the more confused the masses of ice which they separate. This arises from the inequality of the bed and sides of the channel; for thus lines of tension are produced, and across these lines of fracture. Very great fissures appear indeed in all parts of the glacier, but the displacements which these occasion as the masses move onward grow more and more remarkable, because of the additional effect of waste on the surface, in the fissures, and below the glacier.

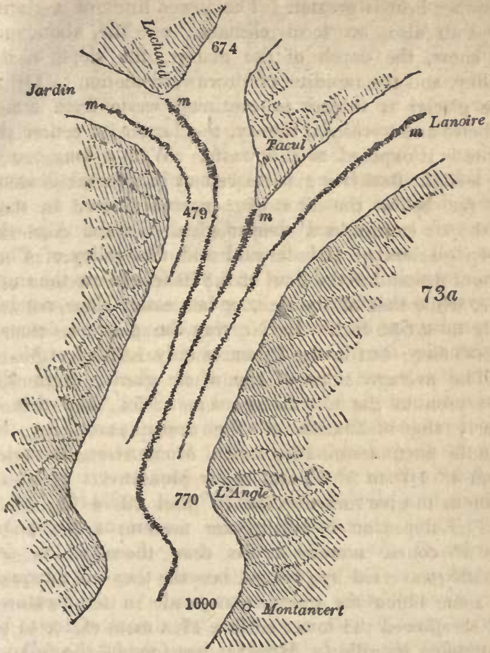
The glacier thus slowly gliding or flowing down its channel is like a huge grinding and polishing mass. Not that the ice of which it consists can wear much even of the limestone and still less of the gneissic bed of an Alpine or Scandinavian valley, any more than pitch can wear hard speculum metal; but the glacier has under it hard stones, which, set as it were in the ice, become as effective agents in wearing away the rock as emery set in the pitch grinds the hardest compound of copper and tin. Nor is it necessary for attrition that the stones should be imbedded; their grinding effect when loose is considerable.

The sides, also, of the glacial valley are worn by similar pressure and similar agency. This is actually seen to be the case at the "angle" on the Mer de glace (Forbes), and in other situations. In fact owing to the circumstance that the glaciers in some seasons extend themselves far beyond their usual flow, and in other seasons retreat within their ancient limits, the scratched, grooved, and rounded rocks which they once covered, and between which they formerly flowed, are visible in many places, and leave no doubt of the power with which glaciers grind their channels.

Some of the materials for this grinding are brought down by the glaciers themselves, on which we commonly see, in the middle, or at the sides, or in both situations, sinuous lines of rock fragments, which, being traced up to their source, are always found to be furnished by rocks on the sides or at the junction of glaciers. These streams of stones are called *moraine*: the lateral streams are furnished by rocks on the side of the flow; a central stream may be formed by the union of two lateral moraines when two glaciers meet and unite, and thus, in the lower part of a glacier, which is formed of many confluent streams of ice, many lines of moraine may be traced. Arrived at the termination of the glacier, these streams lose their individuality for the most part, and constitute a great terminal moraine. Such remain, in many situations, many hundred yards, and even some miles, beyond the present range of the glacier which transported them.

In the diagram (p. 17.) several of the circumstances which have been mentioned are represented. It corresponds to a part of the Mer de glace above Montanvert. Three glacial streams are seen to unite, and three bands of moraine to run down the main glacier (marked *m*). The figures indicate the number of feet in a year which the glacier moves at the point where they are placed. (From Forbes's Travels in the Alps.)

Amongst the blocks brought down in this singular manner by glaciers, without attrition, are many of enormous magnitude; and, as each moraine band is only fed from certain rocks, it is easy to see that each has its own mineral character, and may bring detritus of a totally different quality from even its next in position. Much more, in this respect, may different glaciers disagree. If then, as in Spitzbergen, on the coast of Greenland, and in Tierra del Fuego, the glacier masses break off in icebergs, it is quite to be expected they should, after carrying their loads of rock to greater or lesser distances, deposit them in groups, each having a certain character and com-



bination, just as we see to have been determined by many travellers on the plains of North Germany, Russia, North America, and the regions west and north of the Alps.

The height of the origin of a glacier depends, as already observed, on the elevation of the line of perpetual snow; and this varies, not only with latitude, but by the influence of local causes and peculiarities of climate. In all the northern zones it is above the isothermal lines of 32°, and is so much the more above this line, as the difference between winter cold and summer heat is greater. The lower limit of a glacier depends also on local climates, on the abundance of snow, the depth of the glacier, the slope of the valley, and the rapidity of downward motion : for as the glacier is subject to continual waste from atmospheric and terrestrial agency, the longer its course the more is it exposed to this waste. With a long course on a slight declivity glaciers cannot in general descend so far below the line of perpetual snow, as with a shorter course in a steeper glen. In the Alps the steep glaciers of Grindelwald and the valley of Chamouni descend to the level of 5,300 feet below the snow line, while that of the Aar, on an easier slope, reaches only to 2,650 feet. In Norway the glaciers descend 4,400 feet ; but in the Pyrenees only 1,700 feet.*

The average slope of the whole glacier from the Arveyron to the Col du geant is 8° 52′, and this is nearly the inclination of the upper part. In the middle part, terminating with Montanvert, it varies from 4° 19′ to 5° 5′, and below Montanvert grows so steep as to give measures of 12° and 20° 41′.†

The slopes on which glacier movement is *possible* are of course somewhat less than those which are actually traversed by glaciers, because they are unequal. In some ingenious *experiments* made in temperatures which allowed the lower surface of a mass of ice to be just losing its solidity, Hopkins has found ‡ the following relations between the inclination of the surface on which motion takes place, and the velocity produced. Up to 12° the velocity is *uniform.*

Inclination.	Hourly Motion in Inches.	Inches in 24 Hours
3°	0·31	7·44
6°	0·52	17·28
9°	0·96	22·32
12°§	2·00	–

20° The motion became *accelerated.*

* Hopkins in Proceedings of Geol. Soc. 1852.
† Forbes's Travels in the Alps.
‡ Camb. Phil. Trans.
§ Weight diminished to ½.

On reducing the inclination to 1° there was still a perceptible movement. This table may be compared with Professor Forbes's measures of the velocities observed in the Mer de glace — already given.

Effects of Springs.

Collected in the atmosphere, the rain is filtered through the sandy rocks, passes rapidly by the joints of the calcareous strata, and is stopped by the clays, and by dykes and faults ; it then issuing in springs. But it is no longer the same water : rain water is, indeed, far from being in a state of purity ; it contains always carbonic acid, frequently some muriatic acid or chloride of sodium, besides other irregular admixtures. In passing through the rocks it absorbs lime, oxide of iron, &c., and on issuing in the form of springs, loses its excess of carbonic acid, and again deposits carbonate of lime, carbonate of iron, &c. From some springs the quantity of carbonate of lime deposited is enormous ; with the water of others, sand, gravel, fossil shells, and zoophytic fragments issue. Thus the first operation of water in and upon the earth is the same, viz. to consume away the solid substance of the rocks, and either deposit it in new situations not far from the source, or deliver it to flowing streams to be carried further away.

Springs which have an impeded issue to the surface are the most general cause of landslips : we may con-

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sider the great fall of the Rossberg as a case of this kind, the water entering and moistening a particular layer of strata, all inclined very highly, so as easily to acquire a descending force, if the cohesion of the parts were weakened by interposed moisture.

The spring, or rather river (Arve), which issues from the foot of the Mer de glace, near Mont Blanc, brings a vast quantity of detritus, which the grinding motion of the glacier on its rocky bed had broken and rolled to pebbles.

Effects of Rivers.

A river thus fed by springs of water not pure, partially filled with earthy matter, flowing with various velocities through soil and among rocks of unequal resisting power, and formed of particles of different magnitude and specific gravity, must exhibit in its long course a great diversity of appearances. Some rocks and soils it may corrode chemically, others it may grind away by its own force and the aid of the sand and particles which go with it: from steep slopes it must, in general, transport away all the loose materials; but when its course relents, these must drop and augment the land. The finest particles are first taken up and last laid down; the larger masses make the shortest transit.

Rivers, on whose course no lake interposes its tranquillising waters, may be considered as constantly gathering, incessantly transporting, and continually depositing earthy materials. It is, of course, principally in times of flood that they both gather the most materials, and transport them farthest; yet even in the driest season, the feeblest river does act on its bed, wears by little and little even the hardest stones, and works its channel deeper or wider. This it does, partly by the help of some chemical power, from carbonic acid, and other admixtures, but principally by the grinding agency of the sand, pebbles, &c. which it moves along. In times of flood, these act with violence like so many hammers on the rocks, ploughing long channels on their surface, or whirling round and round in deep pits, especially beneath a fall, or where the current breaks into eddies over an uneven floor of stone. This is admirably seen at Stenkrith Bridge in Westmoreland, under the waterfalls about Blair Athol, and in North Wales, and, indeed, very commonly. Not unfrequently, on mountain sides or tops, far from any stream or channel, phenomena somewhat similar occur, sometimes the effect of rain, sometimes, we may suppose, the remaining evidence of the former passage of running water, when the levels of the country were differently adjusted.

As the slopes are greatest in the upper parts of valleys (generally), and gradually flatten towards the sea, it is commonly observed, that, from all the upper parts of these valleys, rivers abstract large quantities of the finer matter, and in times of inundation, not a little of the coarser fragments of rocks; much of this is deposited in the lower ground, where the current is more tranquil, and generally (unless the river be very deep) slower. We must, indeed, suppose, that every where *some* wearing effect on its bed and sides is produced by every river, even to its mouth; but this effect grows almost insensible far from the high ground which gives birth to the streams; and long ere we approach the estuary, the wide flat meadows, which fill the whole breadth of the valley for miles in length, show what a mass of materials has been drifted away from the higher ground. Finally, where the tides and freshes meet, the sediment of both is disposed to drop; and some rivers may be viewed as sending little or no sediment to the sea.

Thus the whole effect of drainage, including all the preliminary influences of the atmosphere, rain, springs, &c., is to waste the high ground, and to raise the low; to smooth the original ruggedness of the valley in which it flows, by removing prominences and filling up hollows; and notwithstanding the length of years that rivers have flowed, they have, in general, not yet completed this work: they still continue to *add* materials to the lower ground, and, in a few instances, to carry out sediment into the sea.

The whole surface of the earth, then, is changing its level, by the mere precipitations of the atmosphere, and their subsequent effects; the high land sinks, and the low land rises; but what is the rate of this progress, we have no complete means of knowing. Few ancient measures of the height of the land which has been wasted, or the area of that which has been accumulated, are worthy of notice; we are, however, sure, from various causes that many valleys have not been altogether worked out by the rivers now running in them; and some natural chronometers have been pointed out by De Luc and others, which rudely limit the length of time during which rivers have flowed, and might be more usefully employed to determine the rate and amount of fluviatile action.

Rivers certainly did not excavate the whole valley in which they flow, for they have not even removed the diluvial detritus brought into them from other drainages, and heaped on the previously excavated rocks.

Rivers have certainly not excavated more than an inconsiderable part of their valleys, for otherwise the Lakes of Geneva and Constance would have been long since filled by the sediments of the Rhone and the Rhine, which issue from these lakes of that lovely hue and transparency which marks their total freedom from all tinge of earthy impurity. When, indeed, we look at the small but growing deltas of the heads of the English lakes, as Derwentwater, Windermere, or Ulswater, and consider the Derwent or the Rothay in its time of furious flood, we shall be disposed to set a high value on De Luc's opinion, sanctioned by Cuvier, Sedgwick, and others, that these deltas prove the comparatively recent date of the present disposition of drainage on the surface of the earth. Rivers flow in certain channels, because these were previously formed by convulsions, and violent movements of water; they have exerted all their force in merely smoothing and filling the inequalities of their valleys, and this partial labour they have not accomplished. Will any one, after this, require to be told that rivers did not make their own valleys; and only yield to this truth when, on the chalk and limestone hills, hundreds of valleys are shown him, down which water never runs, and which, indeed, have no trace of a channel?

The upfillings of a valley by the operations of a river ever tend to be formed in horizontal laminæ; or at least their surface is generally level in the direction across the valley, whatever undulations exist beneath, and however rapid may be the longitudinal declivity of the valley. This is well seen in many valleys of the Swiss Jura, the Cotswold Hills, &c.

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a. Irregular surface which is the original basis of the valley. *b*. The sediment left in it, with a plane surface *as if* deposited in a lake. *c*. The surface of the valley, uniformly declining among *h*, the bordering mountains.

When the materials are gravel and coarse sand, deposited by an impetuous stream, the general surface may be level, and yet the laminæ beneath are frequently much inclined, with slopes in various directions, as Mr. Lyell has noticed with regard to the detritus left by the stormy waters of the Arve. The same thing occurs in many of the stratified rocks which appear to have been accumulated under violent agitation near the sea-shore. (See Diag. No. 20. p. 61. Vol. I.)

Lakes on the Course of Rivers.

Plane surfaces existing along the course of valleys, are commonly, without further question, supposed to be indicative of the site of ancient lakes, which have been slowly but completely filled: the supposition is often correct, but it is sometimes erroneous. Rapid rivers, which, in times of inundation, drift coarse materials down their rough beds, and deposit them in the expansions of their valleys, are thus partly choked in their courses, and turned into new channels. Thus they wander irregularly over a large area, every where filling it, to about the same height, with a mass of partial deposits, related to the successive positions of the channel, which, when unconfined by man, seeks always the lowest passage. On a cross section of such a valley, these many distinct streams of gravel and sands appear nearly as in the annexed diagram.

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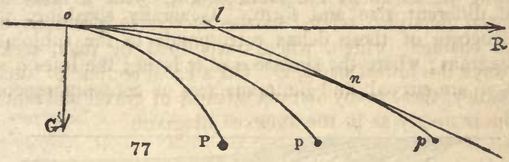
But such a distribution of materials appears not to occur in lakes; whether they receive sediments from gentle streams, rapid rivers, or sudden inundations. The reason of this is the great lateral diffusion of motion in water. Where any great depth of quiet water is interposed on the path of a river, the lacustrine sediments assume various modes of arrangement, depending on their own fineness, and the velocity of the water by which they are hurried along.

Deep Lakes on the Course of a River. — On entering a deep lake, the mingled sediment of a river is subjected to a new influence, — the descending force of gravity, in addition to the direct horizontal force imparted by the current, and the lateral movements which it occasions. Each particle, in consequence, tends to fall from the surface of the water, as it moves forward, or to the right and left of the point of entry of the river, and with an accelerated velocity in the lower part. The path of each particle will be more or less influenced by the direct, lateral, or vertical forces, according to its magnitude and weight. Thus, in the diagram No. 77., which is to represent a vertical section along the path of the river as it enters the lake at the point *o*, P p *p*, particles of unequal magni-



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tude, entering together, describe curves of unequal curvature (they are all related to the same vertical axis, G); the smallest particles being transported furthest, because they have, proportionally, the largest surface, and therefore subside most slowly in the water.

On the horizontal plan (No. 78.) the courses of such deposits are shown to be concentrical, or nearly so, to the point of influx of the river. By such deposits, the Delta of the Rhone in the Lake of Geneva, as well as that of the Derwent in the Lake of Keswick, has been

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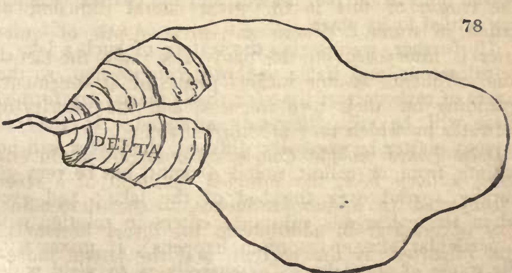

formed; and, in fact, in every lake a similar explanation is found applicable. Returning to the vertical section (No. 77.) we may remark, that the parabolic lines there given, if considered as representing successive depositions, require to be modified above and below: above, by the shifting of (*o*) the point of influx forward; below, by the circumstance that the curve ceases at a certain depth (*n*), when it coincides with the line *n l*, drawn to represent the greatest slope on which the particles will rest. This slope varies somewhat in particles of different size and form. Generally speaking, the structure of these deltas corresponds to the subjoined diagram; where the surface *a a′* is level; the lines *a n′*, *a′ n′* are curved, and lie in surfaces of contemporaneous

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depositions; and the lines *n b*, *n b′* are straight lines corresponding to the angle of rest in deep water.

We may further observe, that the unequal dispersion of the sediments in water causes another modification of the lamination of such delta. Fine clay is spread far in the water, and settles at length in a general thin deposit over the curved and sloping faces *a n b*, and on the bed of the lake *b b″*, after the agitation of the water produced by the inundation has ceased, and the coarser sediment has settled to its place.

If, further, we imagine the waters of such a lake to be calcareous, and liable to slow decomposition, so that layers of carbonate of lime (or shelly marls) are formed, these will be still differently arranged. If the calcareous matter be generally diffused, the layers will not radiate from or collect round a point, but be very generally spread over the bed of the lake; and even when the calcareous substance enters in solution with a particular stream (as often happens), it mixes with the water of the lake so extensively as to yield wider and more regular deposits than those produced by merely mechanical agency.

Shallow lakes, subject to fluctuation, produce on the deposits of coarse gravel and sand, which are brought into them by rivers, an effect intermediate between that of deep water and mere fluviatile currents. The conoidal lamination due to the former is complicated with variation of the point of influx arising from the latter; and thus the upper ends of such lakes become irregular in outline, and are filled by insulated subaqueous banks.

New Lands at the Mouths of Rivers.

The deposition of sediments from a river happens in all parts of a valley, even very near to the sources of the stream, if the slopes of the ground permit; but as towards the sea, generally, the inclination becomes the most gentle, it is there that the finer sediments drop most abundantly.

The cross section of the 'straths' or narrow meadows which are produced in the upper parts of valleys are usually level, or rather a little highest near the edge of the river, and a little lowest where the new surface touches the old (technically 'hard') land. The sediment is rather coarser near the river edge, rather finer at a distance from it, but every where laminated according to the frequency and continuity of the inundations.

Inland seas, which by their position are exempt from strong tides and currents, become filled with river sediments, under the same conditions as large lakes. Their area is contracted, by the addition of new land on the margin, and their depth is lessened by the diffusion of fine sediment over the bed, to various distances, according to circumstances already pointed out while treating of lakes.

Some of the most considerable deltas at the mouths of rivers have been accumulated in seas of this quiet character; as the delta of the Nile, which is a continuation of the long valley of Egypt; the wide sediments at the mouths of the Po and the Adige, the Rhone, the Danube, and the Volga, and the numerous streams which enter the Gulf of Bothnia. The rate of augmentation of the deltas in the Mediterranean may be determined by comparing the descriptions of ancient and modern geographers; and in some cases verified by roads, embankments, and other monuments of ancient civilisation. Mr. Lyell has collected evidence of this nature in proof of the considerable increase of land at the mouth of the Rhone, since the era of Roman power, and even during the last thousand years. "Notre Dame des Ports was a harbour in 898, but is now a league from the shore. Psalmodi was an island in 815, and is now two leagues from the sea. Several old lines of towers and sea-marks occur at different distances from the present coast, all indicating the successive retreat of the sea, for each line has in its turn become useless to mariners; which may well be conceived, when we state that the Tower of Tignaux, erected on the shore so late as the year 1737, is already a French mile from it."—(Princip. of Geol., book ii. ch. iv.)

Lower Egypt is the gift of the Nile; and Herodotus estimates the sediments borne by the waters of that river to be so abundant, that if diverted into the Arabian gulf (Red Sea), they would fill it up in 20,000, or even 10,000 years. But the further growth of the great Nilotic delta is checked by a powerful littoral current, which washes the African coast from Gibraltar to Egypt. The accession of new land on the coasts of the Adriatic is perfectly known, since the Augustan days of Rome, and the rate of increase is inferred to have been even augmented during the last 200 years. For by Prony's account (Cuv. Disc. sur les Rev. du Globe), the shore was 9000 or 10,000 metres from Adria in the twelfth century; 18,500 metres in the year 1600; and between 32,000 and 33,000 metres at present; which gives an average yearly increase of breadth of new land of 25 metres from 1200 to 1600, and 70 metres from 1600 to 1800. This augmentation may probably be ascribed partly to the shallowing of the whole upper end of the Adriatic, and partly to the alterations of the system of internal drainage, whereby the rivers, enclosed in extensive embankments, are prevented from depositing much of their sediment upon the ancient alluvial lands. "From the northernmost point of the Gulf of Trieste, where the Isonzo enters, down to the south of Ravenna, there is an uninterrupted series of recent accessions of land, more than 100 miles in length, which within the last two thousand years have increased from *ten to twenty miles in breadth.*"—(Lyell, book ii. ch. iv.)

The surfaces of deposition from rivers thus entering quiet seas are in general inclined at a very moderate angle: at the mouth of the Rhone the water deepens gradually from four to forty fathoms, in a length of six or seven miles ($\frac{36}{5720}$), or 1 in 160, a "dip" less than the average inclination of our so-called "horizontal" strata. Reasons are assigned for adopting the opinion that the Adriatic, now so shallow, was once a deep sea; if so, the sediments on its bed, raised into dry land, would constitute a modern formation equal in importance to a large part of the subapennine tertiaries, and, according to the testimony of Donati, very similar to them in mineral composition, and the arrangement of their organic contents. The sediments consist of mud and calcareous rock, with shells grouped in families, as we often find them in ancient strata. The deposits from the Rhone are ascertained to be in a considerable degree calcareous, sheets of limestone indeed; and the mud of the Nile contains nearly one half of argillaceous earth, about $\frac{1}{4}$th of carbonate of lime, and $\frac{1}{10}$th of carbon, besides silica, oxide of iron, and carbonate of magnesia. (Girard, quoted by Lyell.) Materials of this description may be deposited together; but little doubt can exist that, during their solidification, the arrangement of the particles may be so influenced by peculiar attractions, as to exhibit many of the circumstances noticed among old sedimentary rocks, as concretions of limestone, siliceous nodules, segregations of oxide of iron, &c.

These recent deposits sometimes are laminated like the old rocks. De Luc notices, near Groningen and Enckhuysen, the division of the silt deposit into layers, by the annual growths of grassy turf buried in sediments. At Enckhuysen, he also observed between the layers ("couches") of sediment, *sand and shells*, and very justly calls attention to the value of this example of the different effects which may be occasioned by currents in the modern ocean, comparable to the appearances in the solid crust of the globe. (Lettres sur l'Histoire de la Terre et de l'Homme, vol. v. p. 289.)

The general result of atmospheric and fluviatile action is to equalise the levels of the land, to smooth and mask the original inequalities of the surface, partly to deepen, but principally to elevate the valleys. The sediments which remain on the course of rivers, are all more or less inclined, and thus, from their sources down to the sea, and into the sea, a series of inclined deposits, pebbly, sandy, argillaceous, and calcareous, may be always observed. These deposits are subject to much irregular wasting, by inundations and change of the river channels, while unconfined by art; when embanked, a new order of phenomena arises.

In rivers whose mouths are carried farther and farther continually into the sea, the moving force of the stream would be lost, did not the level of the water rise between the sea and the upland. In a state of nature, this may be sometimes accomplished by successive depositions of sediment over all the parts of a large surface; but there are many cases in which it is evident that rivers tend to embank themselves, by depositing along the sides of their channels a greater proportion of sediment than falls elsewhere. This effect is most striking along streams which bear gravel and coarse sand, as near Kirkby Lonsdale, and in all mountainous countries. Rivers which are forced by artificial barriers to flow in one channel, across a flat alluvial tract, to the sea, ever tend to raise their own beds, and the embankments, rising with them for the protection of the marshes, exhibit in the Po and the numerous rivers of Holland, and the English fens, the singular spectacle of vast volumes of water, flowing on levels many feet or yards above the cultivated fields, and even higher than the houses, which are often placed below the shelter of the dangerous bank. Hardly any thing can be imagined more awful than the bursting of river banks in the fen lands of Norfolk, Cambridgeshire, and Lincolnshire.

Estuary and Shore Deposits.

Rivers which discharge themselves into the ocean, where tides and currents break with a certain regularity the quiet of its waters, exhibit always at their mouths, and often along the lower part of their channels, another set of phenomena.

Where the tide enters a river's mouth, and periodically combats the freshes, these are "backed" to certain distances, their motion is nearly destroyed for a time, and the sediment, which was only suspended by the agitation of the water, is dropped in the interval of quiescence. The stronger the current from the land, the further toward the open sea are its sediments carried, so that in many cases large quantities pass beyond the estuaries and float away on the heavier salt water, even to hundreds of miles from the coast. (Vol. I. p. 342.)

It is easy to perceive that, by this process, every river connected with a tidal sea is continually repelling the salt water, and making new land by its fresh-water deposits. Thus it happens that many towns to which the tide formerly reached, in the days of Roman sway, as Ribchester, Norwich, York, are now wholly or partially deserted by it, and large breadths of marsh land occupy the sites of ancient tide lakes. It is, however, true, that the tide waters themselves have contributed some part of the sediment which forms the wide marsh lands by the Thames and the Medway, the enormous breadths of fen land in Lincolnshire and Cambridgeshire, and the warp or silt lands on the Trent, Aire, Ouse, and Derwent. The latter cases are very instructive, because, by studying in connection the operation of the sea on the coast of Holderness, and in the tributaries of the Humber, we see very plainly an important benefit arising from the enormous waste of that ill-fated coast ($2\frac{1}{4}$ yards per annum for 30 miles from Kilnsea near Spurn Point to Bridlington). The mean height of this wasting cliff being taken at only 10 yards, the total quantity of fine sediment, coarse sand, pebbles and boulders, falling into the sea in one year $= (1760 \times 30) \times (10 \times 2\frac{1}{4}) = 1{,}188{,}000$ cubic yards. Now, though not all this mass of sediment must be supposed to enter the Humber, a considerable portion of it does, and is turned to good account by the industrious and intelligent inhabitants, in the practice of warping. This consists essentially in admitting the muddy waters of the tide at its height, and especially in spring tides, to flow through proper channels over the low land adjoining the rivers, so that by stagnation it may drop its sediment, and again be returned to the Humber. By frequent repetition of this simple process, the hollow places near the rivers which are connected with the large estuary of the Humber are filled up, and thousands of acres of land raised in level one foot, or eighteen inches; and by the addition of most excellent soil augmented in value from a mere trifle to above the average of the country. The annual waste of the Holderness coast alone would cover to the depth of one foot 3,564,000 yards, or about 737 acres. It is often imagined that all the "warp" of the Yorkshire rivers descends with the fresh waters: this is so far from the fact that it is in dry seasons, when the freshes which bring no sediment do not dilute the rich tide water, that the process is most successful. The quantity of sediment contained in the water in a dry summer is great, and chokes the channel of the Dun about Thorne; but in winter the floods clear it away.

The water of the Rhine transports, according to Mr. Horner's experiments at Bonn, about $\frac{1}{16000}$th part of its own volume of mud; and the extent of alluvial land, at the mouth of this and other German rivers which enter the North Sea, shows that in some earlier times the conditions of that sea were such as to favour accumulation, and permit of secure embankments. But, for some hundreds of years, a different scene has been presented; both natural and artificial barriers have yielded to the increased pressure of the sea, large tracts of the main land are lost in the waves, while the islands that still fringe the coast, relics of a once continuous tract, have been diminished, and are still undergoing waste. In 1421, the wide surface of the Bies Bosch was overwhelmed; in the thirteenth century the Zuyder Zee was excavated; and since the year 800, Heligoland, with other islands, has been nearly swept away; and, from Belgium to Jutland, the whole coast has more or less changed its form in consequence of the incessant attack of the sea. The history of Nordstrand and other islands belonging to Sleswig, formed of alluvial land, which was deposited, fortified, and afterwards devastated by the sea, as given by De Luc (Geol. Travels, vol. i.), is extremely instructive, and places in a clear light the contrast between what may be termed the ordinary processes, whereby sediment is accumulated, and the extraordinary and wasteful violence of the North Sea when swollen by high tides, and urged by powerful north-westerly winds.

By Capt. Denham's survey of the estuary of the Mersey, it appears that a cubic yard of water of the flood tide holds 29 cubic inches of mud in suspension, and a cubic yard of water of the ebbing tide 33 inches; and the quantity of water moving up and down is such, that with every ebb tide 48,065 cubic yards of sediment pass out of the estuary, and are detained by the banks outside the Rock Narrows, excepting that part which the succeeding ebb tide disturbs. The excess of silt thus accumulated from 730 refluxes of the year's tides amounts to 35,087,450 cubic yards; and the annual tangible deposit over a certain area (allowance being made for shrinking to half its bulk) is estimated at 11,695,817 cubic yards. The cross set of the Irish Channel currents limits the extension outwards of the shoals.

The proportion of sediment thus found in the Mersey (33 cubic inches in a cubic yard $= \frac{1}{1414}$, and 4 cubic inches the quantity really deposited $= \frac{1}{11664}$,) may perhaps exceed the average for British estuaries, but is much below some estimates, or rather conjectures, collected by Mr. Lyell, from Rennell, Sir G. Staunton, and others. Mr. Everest found in the water of the Ganges, during rains, $\frac{1}{856}$th of its volume of mud; and the total annual discharge of sediment into the Bay of Bengal 6,368,077,440 cubic feet (=235,854,720 cubic yards). (Biblioth. Universelle, 1834). In the Severn Mr. Ham found on an average 40·3 grains of sediment in an imperial gallon of water, weighing about 10 lbs., or 70,000 grains—proportion of weight as 1737 to 1: of bulk as 6948 to 1 nearly. (British Association Reports, 1837.)

If researches of this nature had been prosecuted in various quarters of the globe, and on rivers flowing over different classes of rocks, the results would have been of great value in geological reasoning.

If the country drained by the Ganges is 300,000 square miles, its average waste, from Mr. Everest's data, would appear to be 78·6 cubic yards per square mile of 3,097,600 square yards, $= \frac{1}{4000}$ of a yard in depth, which is about $\frac{1}{111}$th of an inch per annum from the whole surface of drainage! In 8000 years this would be equal to the mass of the English tertiaries, assumed to be on average 300 feet thick, and to have a surface of 6000 square miles. The Brahmaputra is supposed to discharge as much sediment as the Ganges.

On the narrow bed of the quiet Adriatic we behold the accumulation of conchiferous mud, hardly different from the subapennine tertiaries which have formerly been raised from out of the Mediterranean; in the wider Bay of Bengal the diffusion of river sediments is complicated by tidal action and periodical winds; and the North Sea gives us in addition, all the variations of opposing and concurrent tides, entering from opposite points, and diverted into a variety of channels by the form of the coast and the inequalities of the sea bed. How various are the materials therein deposited! Boulders of granite and other rocks, drifted from the Cumbrian mountains, fall from the Yorkshire cliffs, mixed with oolitic limestones, and chalk and flints; blocks of Scandinavian rocks are mixed with the silt along the coasts and islands of Denmark; the Thames brings tertiary, the Tees secondary, the Dee primary detritus. And all these ingredients, distributed over the shallow bed by violent currents and storms, mix with volcanic sediments from the Rhine, cretaceous mud from the English Channel, and organic exuviæ drifted from the polar circles, or perhaps brought by the gulf stream from the tropical shores of America.

This remarkable sea bed is so nearly level, that its slight inequalities are indiscernible when drawn to a true scale, yet it is really channelled and undulated, and liable to change in the form of its surface, since we are informed that currents have cut through Heligoland a channel 60 feet in depth.

Upon such a surface some organic bodies will be entombed entire, where they lived and as they died, (oyster-beds for example, comparable to the fossil oyster-beds in the oolitic system,) others will be displaced, and floated to various distances, and deposited in unequal states of imperfection. Some bivalve shells will be found in the rocks which they have bored, others with valves just held by the ligament, or widely separated, or broken among pebbles; fishes entire, or disintegrated; their scales and teeth drifted away by the currents, and mixed in various combinations with the unsettled sediments.

Now, most or all of these circumstances may be paralleled among many of the strata; especially among the tertiary and certain parts of the oolitic systems of strata; and a benefit would be conferred on geology if a careful and accurate survey were made of the mineral and organic contents of the whole bed of the German Ocean, for which object its shallowness (it nowhere exceeding 30 fathoms in depth between the Humber and the Elbe) offers unusual facilities.

Lacustrine Deposits.

Until the publication of Cuvier and Brongniart on the Environs of Paris, the attention of geologists was but feebly turned to the study of the numerous fresh-water deposits, from which, chiefly, we are to learn the ancient condition of the land, as the stratified marine sediments give us information of the contemporaneous operations in the sea. The general scale of geological time most certainly is founded on the series of marine deposits; but our views of the changing conditions of the globe will be very imperfect if we are not able to arrange on the same scale the monuments which remain of the contemporaneous operations on the land.

At certain points in the series of tertiary strata this can be done with certainty, or probabilities of various value, by the legitimate process of observed *interstratification*. Marine post-tertiary deposits are sometimes associated with lacustrine sediments, in such a manner as to determine a few points of union in times approaching our own day.

But, for a very large proportion of lacustrine formations, the important data of interposition among marine strata are wanting, and we are only able to affirm that the fresh-water sediments are of a date *posterior* to a certain marine formation, because they *rest upon it*.

Some few of these lacustrine formations can, by some monuments of art and civilisation, be proved to belong to the period since the creation of man, or even be limited within certain historical dates; but there remains a large class of desiccated lakes whose antiquity must remain indefinite, both as regards the historical and geological scales of time, unless we can find tests independent of successive deposition, and of remains of human art, and yet comparable with natural monuments both in the ancient and modern, the geological and the historical, ages of the world.

These are the organic remains of plants and animals; and before employing their powerful and abundant testimony in solving the difficulties which attend a classification of lacustrine deposits, we must be satisfied on two points.

1. That faithful observation and correct inferences have established the fact that to every successive geological period belonged characteristic groups of marine plants and animals, which, in every region yet explored, may by comparison of selected genera and species, be discriminated from marine groups of earlier and later date, whose *remains are buried in that region.*

2. That through the whole series of strata, the organic productions of the land and fresh water, which are mixed with or interposed in beds among marine strata, present variations of form and structure similarly related to geological time.

On these points the reader who consults Vol. I. chap. v. of this work, and considers the drawings and notices of the organic remains of the several systems of strata, will probably need no farther proof, except what the following investigation may yield. There remains, then, only the difficulty of deciding how far the relics of plants, shells, fishes, reptiles, and quadrupeds, which occur in the lacustrine sediments of all ages, are *sufficiently numerous and characteristic* to justify positive inferences. This must be left to the judgment of geologists in each particular case, attention being always directed to the circumstances which accompany the inhumation of terrestrial and aquatic beings in the present condition of nature; for it is very certain that only a small proportion of land or fresh-water plants, molluscous, articulated, or vertebral animals, is entombed in lacustrine sediments.

Purely lacustrine deposits are almost unknown among any of the stratified rocks of earlier than tertiary date. The laminated carboniferous limestones of Burdie house, near Edinburgh, can hardly be admitted an exception, any more than the calcareous beds of Ardwick and Lebot wood, which lie nearly at the top of the coal formation of England. These deposits may indeed be thought to mark the influence of fresh water predominating over that of an estuary, such as we suppose to have received the sediments and vegetable relics which constitute the coal formation above millstone grit.

Fresh water products again appear in the midst of the oolitic strata of Yorkshire, accompanied by circumstances almost perfectly comparable to those which characterise the true coal formations; the same fact is repeated in the strata of the Wealden; but in each of these instances the observers most attentive to the phenomena have decided that they indicate fluviatile not lacustrine accumulation. The argillaceous and calcareous strata of Purbeck and the upper Wealden beds certainly come nearer to the notion of quiet sediments, collected in a lake, than any other deposits of secondary or earlier date.

It is therefore very interesting and important to study with care and perseverance the varied mineral characters of the supracretaceous lacustrine sediments; and to compare the organic contents of those whose place on the scale of marine strata is known, in order to obtain rules for judging of the relative age of others which are less favourably circumstanced. Some of the results of this study we propose to exemplify, in the following brief notices of remarkable lacustrine formations.

Upon a general review of the ossiferous deposits of Europe, we discover two very distinct assemblages of animal remains, belonging to two obviously distinct and widely separated geological periods, both anterior to the completion of the present arrangement of organic life, and main features of physical geography in these regions; viz. the eocene or lower tertiary mammalia and the animals of the diluvial period. Between these two groups, are many assemblages of intermediate character, and intermediate geological position (as in Touraine), and later than all of them are other deposits which (imperfectly) unite the diluvial to the existing fauna. The mammalia whose remains lie in the lower tertiary rocks may be considered as having lived on the land previously to the origin of these strata; and those whose relics fill caverns and gravel-beds obviously belong to a surface of the earth which has been modified by subsequent revolutions. We have therefore the following general classification of the results arrived at in studying fossil mammalia: —

Modern period -	Pachydermata almost lost; *ruminant* quadrupeds assume preponderance, as *stag*, ox, sheep, &c. wolf.
Diluvial era -	Pachydermata abound, mostly of *living* genera; as *mammoth*, hippopotamus, rhinoceros, tapir, horse, pig; large feline and bovine quadrupeds and deer abound.
Tertiary period -	Pachydermata of *extinct* and *living* genera abound; as mastodon, hippopotamus, rhinoceros, *dinotherium*, anthracotherium, horse, deer; feline quadrupeds not rare.
Supracretaceous era -	Pachydermata of *extinct* genera first appear, especially *palæotherium*, anoplotherium, lophiodon.
Secondary period -	Marsupial quadrupeds * occur in one place (Stonesfield).

Mr. Lyell's classification of tertiary strata (vol. i. p. 267.) may be easily reduced to this scale, with sufficient accuracy for our present purpose, by reading for diluvial, newer pleiocene (according to the tendency of book iv.

* The true relations of the Stonesfield fossil jaws referred by M. Cuvier, Mr. Owen, and M. Agassiz to marsupialia, may now be regarded as settled.

chapter xi. of the Principles of Geology), for supra-cretaceous eocene, and by uniting the meiocene and older pleiocene periods. Upon this basis it appears worth while to inquire how far the shells found in lacustrine sediments support the inferences of the change of organic life, since the age of the chalk, which have been drawn from marine remains and bones of terrestrial quadrupeds, though there is reason to regret the neglect which this important subject of research has experienced. Contemporaneous with the marsupials of Stonesfield, and with the extinct dinosaurians of Sussex and Yorkshire, we have freshwater shells in the oolitic coal series of Whitby (Unionidæ) and others of like affinities in the Wealden beds.* A valuable addition to our knowledge of the lacustrine deposits of Purbeck has lately been given by Professor E. Forbes.† These truly lacustrine beds rest without gradation on the truly marine beds of the Portland oolite. These lowest freshwater beds contain modern genera, viz., cyprides, valvata, limnæa; above them are the well-known dirt beds with the bases of cycadeæ *in situ;* above the dirt beds are cypridiferous shales, covered by a varied series deposited in *brackish* water, and containing rissoæ and protocardia, and serpulites. Over these come again purely freshwater beds marked by cypris, valvata, and limnæa. Then a thin marine band,—followed by another group of freshwater beds with cypris, valvata, paludina, planorbis, limnæa, physa, cyclas, all different from their congeners in the beds below. With them are some vesicles of chara (gyrogonites). Marine beds cover these, and are followed by beds of freshwater and brackish origin, with the same cyprides as below, some fishes, &c. Again marine beds and brackish beds, and a third series of freshwater strata with a new series of fossils, cyprides, paludina, physa, limnæa, planorbis, valvata, cyclas, unio, — all modern genera. Marine strata come on above.

* Mantell has described a large Unio from these beds.
† Brit. Association Reports, 1850.

"So similar are the generic types of these mollusca to those of tertiary freshwater strata and those now existing, that had we only such fossils before us and no evidence of the infraposition of the rocks in which they are found, we should be wholly unable to assign them a definite geological epoch." In the lapse of time during the deposition of these Purbeck strata, there was no great physical disturbance *there*, nor were the sediments much varied in mineral character, nor were the generic forms changed, and these forms are yet continued in other species which are in existence at the present day in the same physical region. The scale of lacustrine life, if formed on the mollusca, would not be marked by generic steps, as the contemporaneous scale of marine life is. Perhaps we may admit a similar result in the case of aquatic and land insecta*, as compared with marine crustacea.

Eocene, or lower tertiary Period.

The freshwater sediments of the Paris basin, studied in connection with those of Auvergne, Velay, and Cantal, offer a very complete view of the eocene lake deposits, and lead to the conclusion that the marine and freshwater strata of that basin are to be considered as marking sometimes the independent action of the sea and land floods in one basin, and sometimes their periodical alternation; the land floods always coming from the south, and the marine sediments from the north or west.

The gypseous deposit of the Paris basin is a repository of many extinct species of quadrupeds, while of birds 10 species, and several fishes and reptiles, also extinct, remain to augment the value, and complete the evidence presented by these precious relics. Four fifths of the quadrupeds belong to the division of pachydermata; and nearly all the species are such as might be supposed

* See Brodie's Fossil Insects.

habitually to frequent the margins of rivers and lakes. Among them are

Cheiroptera, Vespertilio Parisiensis. —*Carnivora*, Nasua; Viverra Parisiensis, and 2 others; Canis, 2 species.—*Marsupiata*, Didelphis Cuvieri, and another.—*Rodentia*, Myoxus, 2 species; Sciurus.—*Pachydermata*, Adapis Parisiensis; Chæropotamus Parisiensis; Anoplotherium commune, A. secundarium; Xiphodon gracile; Dichobune leporina, D. murina, D. obliqua; *Palæotherium magnum, P. medium, P. crassum, P. latum, P. curtum, P. minus, P. minimum, P. indeterminatum; Lophiodon——.

Among the reptiles are trionyx Parisiensis, emys (several species) crocodilus.

Palms and other endogenous plants accompany these remains.

In this list of undoubtedly eocene quadrupeds, we remark, with interest, first, the total absence of ruminant animals; secondly, the great predominance of the pachydermata; thirdly, the deficiency in this group of the elephant, rhinoceros, hippopotamus, mastodon, and horse; and, fourthly, the deficiency of large feline beasts. By all these characters the eocene deposits differ widely from those which have been generally called diluvial.

The quarries of Binstead, and cliffs near Ryde, have yielded to Mr. Pratt, Mr. W. D. Fox, and Mr. W. V. Harcourt, bones of palæotheria, anoplotheria, chæropotamus, and perhaps dichobune, as Mr. Owen has recently stated to the Geological Society (Proceedings, Nov. 1838). The species are

Palæotherium medium.	Anoplotherium commune.
———— crassum.	———— secundarium.
———— minus.	Chæropotamus ———.
———— curtum.	Dichobune ? (This was formerly described as a species of moschus.)
———— a new species.	

The agreement of this list with that of the animals of the corresponding beds in the Paris basin is remarkable.

All the land and fresh-water shells of the basins of Paris and Hampshire belong to *extinct* species. In Hordwell cliff Mr. Lyell found vivipara lenta, melania conica, melanopsis carinata, M. brevis, planorbis lens, P. rotundatus, Limnæa fusiformis, L. longiscata, L. columellaris, potamidum margaritaceum, neritina, ancylus elegans, unio solandri, mya gregarea, M. plana, M. subangulata, and 2 species of Cyclas. (Geol. Trans. 2d Series, vol. ii.)

The coeval beds of the Paris basin contain Cyclostoma mumia; Limnæa longiscata, L. elongata, L. acuminata, L. ovum, bulimus pusillus, &c.

Middle Tertiary Period.

In the upper fresh-water beds of the Paris basin (considered eocene by Mr. Lyell) occur many shells closely approaching recent species, as well as those of the true palæotherian age. The series is cyclostoma truncatum, C. elegans antiquum; *Potamidum Lamarckii, Planorbis rotundatus*, P. *cornu*, P. prevostinus; limnæa cornea, L. fabulum, L. ventricosa, L. inflata, L. cylindrus; *Bulimus pygmæus, B. terebra*; paludina carinata; Pupa Defrancii, P. muscorum; Helix lemana, H. desmarestina.

In the fresh-water limestone of Saucats, near Bordeaux (considered to be of meiocene date by Mr. Lyell and M. Deshayes, but ranked with later deposits by M. Dufrenoy,) are found Cyrena Brongniarti, *Planorbis rotundatus*, and Limnæa longiscata.

A strong analogy to existing as well as extinct species appears in the fresh-water deposits of Aix in Provence, where, according to Lyell and Murchison, the series of strata in descending order is as follows: —

150 feet of white calcareous marls and limestone, calcareous and siliceous millstone and resinous flints,— containing *Potamidum Lamarkii, Bulimus terebra, B. pygmæa;* Cyclas gibbosa, and another species.

The subjacent strata (marls, with fishes, plants, &c.) run out into a terrace, beneath which gypsum is extensively worked. "In this upper gypsum fossil insects occur exclusively in a finely laminated bed of 2 inches in thickness: still lower are two other ranges of gypsum, the upper one of which alone is worked; the marls associated therewith contain nearly as great a quantity of fishes as those of the upper calcareous zone. Beneath these are beds of white and pink coloured marlstone and marl, *inclined at 25° to 30°*, containing *Potamidum Lamarckii*, and Cyclas aquæ Sextiæ; and these pass downwards into a red sandstone and coarse conglomerate. The fundamental rock of the whole district is a secondary limestone, with belemnites, gryphites, and terebratulæ." In the contemporaneous lignites of Faveau, *Planorbis cornu, P. rotundatus*, Melania scalaris, cyclades, and a unio occur; thus rendering the resemblance of the testacea of this deposit to those of the Upper Parisian freshwater beds very striking.

The insects of this deposit consist of Coleoptera 20 species, Orthoptera 8, Hemiptera 20, Neuroptera and larvæ, Hymenoptera 8, Lepidoptera 2, Diptera 15; there are also Arachnida. In the opinion of Marcel de Serres and Curtis, they are almost entirely included in genera now living in the south of Europe; and several species, as Brachycercus undatus, Acheta campestris, Forficula parallela, and Pentatoma grisea, are supposed to be identical with living types.

The freshwater beds of Alhama yielded to colonel Silvertop —

Planorbis rotundatus of the Isle of Wight.
———— new species.
Bulimus pusillus.
Paludina pusilla.
Paludina desmarestina.
———— pyramidalis.
Ancylus.
Cypris.
Limnæa.

And at Teruel, Aragon, occurs —

Limnæa pyramidalis.

In the freshwater beds of Cantal, according to Lyell and Murchison, are found —

Potamidum Lamarckii.

Limnæa acuminata, L. columellaris, L. fusiformis, L. longiscata, L. inflata, L. cornea, L. fabulum, L. strigosa, L. palustris antiqua.

Bulimus terebra, B. pygmæus?; B. conicus.

Planorbis rotundatus, P. cornu, P. rotundus.

Ancylus elegans.

At Montabusard, a league west of Orleans, in marls with Limnæa and Planorbis, at a depth of 18 feet, bones of land mammalia were found, belonging to cervus, rhinoceros, mastodon tapiroïdes, palæotherium, and lophiodon. The deposit is thought to be younger than the millstone freshwater beds of Paris. In freshwater beds in the Orleannois, are found Mastodon angustidens, M. maximus?; Hippopotamus, Rhinoceros incisivus, R. minutus, Dinotherium giganteum, Canis, 2 rodentia, and 1 ruminant.

Lacustrine deposits of undoubtedly meiocene age are scarcely known; the list of quadrupeds of this period must therefore be chiefly collected from the marine beds of Touraine, Bourdeaux, Dax, &c.

In the marine beds of Touraine, the following mammalia are found:

Mastodon angustidens.
Hippopotamus major.
——— minutus.
Rhinoceros (large).
——— minutus.
Dinotherium giganteum.
Anthracotherium.
Palæotherium magnum.
Equus.
Lepus.
Cervus, 2 species.

If this list be compared with that of the Paris basin, we perceive, that mastodon, hippopotamus, rhinoceros, dinotherium, anthracotherium, and equus, are introduced among the pachydermata, but without excluding the palæotheria, and that ruminant quadrupeds appear.

At Eppelsheim, on the Rhine, the sandy deposit has yielded a large suite of animal remains, now in the museum at Darmstadt, which present a general analogy to those of Touraine, but possibly are of somewhat later date. Among them are —

Carnivora - Gulo antediluvianus.
Felis aphanistes.

	Felis ogygia.
	—— prisca.
Rodentia -	Palæomys castoroides.
	Aulacodon (Chelodus) typus.
	Chalicomys Jägeri.
	Spermophilus superciliosus.
	Myoxus (Arctomys) primigenius.
	Cricetus (vulgaris ?) fossilis.
Ruminantia -	Moschus antiquus.
	Cervus anocerus.
	——— brachycerus.
	——— trigonocerus.
	——— dicranocerus.
	——— curtocerus.
Pachydermata -	Rhinoceros Schleiermacheri.
	———— incisivus.
	———— leptodon.
	Mastodon angustidens.
	———— arvernensis.
	Equus caballus primigenius.
	——— mulus primigenius
	——— asinus primigenius.
	Tapirus priscus (Lophiodon Cuv.)
	Lophiodon Goldfussii.
	Sus antiquus.
	—— palæochærus.
	Dinotherium bavaricum.
	————— giganteum.
Edentata - -	Manis gigantea.

At Georges Gmünd, near Roth, beds of sandy marl and whitish concretionary limestone crown low hills of keuper sandstone, and contain subordinate beds of calcareous, ferruginous, and bony breccia.

The catalogue of the bones found at this place by Count Munster and other observers, is thus given by Meyer (*Palæologica*, 1832) : —

Mustela, new species.
Ursus spelæus.
A new species of carnivora.
Mastodon angustidens.
———— arvernensis.
Rhinoceros tichorhinus.
———— incisivus.
Dinotherium bavaricum.
Lophiodon, 2 species.
Palæotherium magnum.
————— aurelianense.
Anthracotherium.
Chæropotamus Sommeringii.
Cervus.

In Mr. Murchison's account of Gmünd (*Geol. Proc.*

1831), it is said that Mr. Clift has also identified fragments of the teeth and bones of the hippopotamus and ox. From these data the deposit of Gmünd appears to belong to the middle part of the tertiary series.

The slaty marls and limestones of Oeningen, some of them bituminous and fetid, which rest upon the "molasse" of the Rhine valley, contain plants, insects, one shell, numerous fishes, some reptiles, and mammalia, of which the following is a synopsis, from Meyer, Murchison, &c.

Mammalia: —
- Vespertilio murinus? v. fossilis.
- Vulpes fossilis. Mantell.
- Mus musculus fossilis.
- Myoxus.
- Lagomys.
- Anoema oeningensis. König.

Reptilia: —
- Chelydra serpentina. Bell.
- Salamandra gigantea.
- Triton palustris?
- Rana.
- Bufo.

Fishes (Agassiz): —
- Leuciscus pusillus, heterurus.
- ——— oeningensis.
- Tinica leptosomus, fuscata.
- Aspius gracilis.
- Rhodius latior, elongatus.
- Gobio analis.
- Cobitis centrochir, cephalotes.
- Acanthopsis angustus.
- Lebias perpusillus.
- Esox lepidotus.
- Perca lepidota.
- Cottus brevis.
- Anguilla pachyura.

Mr. Murchison's examination of Oeningen led him to believe that it was to be referred to one of the most recent tertiary æras (*Geol. Proc.* vol. i. p. 169. and 330.): but M. Agassiz, finding all the numerous fishes of this deposit to be of extinct species, regarded it as of higher antiquity than was generally supposed; and as both the tortoise (chelydra serpentina *Bell*) and the fox are extinct species, while the analogies offered by the insects, plants, &c., are in most instances merely generic, this may prove the most satisfactory conclusion.

Insecta -	Formicidæ, hymenoptera, libellulidæ.
	Anthrax, cimex, coccinella, blatta, vespa.
Mollusca -	Anodon Lavateri. Al. Brong.
Plants -	Fraxinus rotundifolia? Lind.
	Acer opulifolium? a. pseudoplatanus?
	Populus cordifolia.

Lakes of the Pleiocene and Diluvial Period.

In this series of deposits, we hardly ever meet with limestone strata, comparable to those of older date ; there are sometimes about the accumulations such considerable marks of local violence of water, as to render it doubtful whether the bones and shells have not been drifted from other situations. The löss beds of the Rhine probably belong to this period.

In the newer pleiocene deposits of the valley of the Elsa in Tuscany, which consist of several hundred feet of marl, and shelly travertins disposed horizontally, six *living* species of testacea were recognised by M. Deshayes: viz. *Paludina impura, Neritina fluviatilis, Succinea amphibia, Limnæa auricularis, L. peregra, and Planorbis carinatus.* (Lyell, book iv. ch. xi.)

The upper Val d'Arno has yielded in its insulated freshwater deposits a few apparently lacustrine shells (anodon, paludina, neritina), and a vast number of mammalia : of which the following is a list (principally taken from Mr. Pentland's communication to Mr. Lyell) : —

Feræ -	- Ursus spelæus.
	——— cultridens.
	Viverra valdarnensis.
	Canis lupus ?
	Canis ——.
	Hyæna radiata.
	——— fossilis.
	Felis, new species.
Rodentia -	- Hystrix.
	Castor.
Pachydermata -	Elephas indicus (or E. primigenius ?)
	Mastodon angustidens.
	———— tapiroides.
	Tapir.
	Equus.
	Sus scrofa.
	Rhinoceros leptorhinus.
	Hippopotamus major.
	———— fossilis.
Ruminantia	- Cervus euryceros ?

Cervus valdarnensis.
———, new species.
Bos urus.
—— taurus.
—— bubalo affinis.

Cuvier also mentions the bones of a lophiodon from Val d'Arno. There is no geological evidence of the age of this deposit, except what its organic contents give. Mr. Lyell ranks it as meiocene: but, to judge from the list of mammalia, we should be disposed to place it in a later geological period; for here are no palæotheria nor anoplotheria of the Parisian eocene beds; no dinotheria or anthracotheria of the meiocene strata of Touraine, Kāpfnach, &c.; while on the other hand, elephas indicus, hyæna radiata, and sus scrofa, if all living species! and Ursus spelæus, U. cultridens, Hyæna fossilis, Cervus euryceros, Bos urus, B. taurus, — all frequent in caverns and diluvial beds, &c., give to the list of animals a very modern aspect. By some authors (Meyer) the elephant of Val d'Arno is considered the same as that of the ordinary diluvium, and by Nesti it is called a new species (E. meridionalis).

The series of deposits in the upper Val d'Arno is as under: —

Upper layer -	Thick beds of yellow argillaceous sand.
Second - -	Thick masses of pebbles.
Third - -	Yellow sand, several fathoms thick, the middle and lower parts rich in bones.
Lowest bed -	Thick blue argillaceous marl, with mica, with bones in the upper part.

The pebbles are largest and most numerous towards the north; the coarse sand abounds in the middle, and the finer sediment in the southern part of the basin; the sands and blue marls lie commonly horizontal. The bones lie in the middle of the valley, on the right side of the Arno.

The lower Val d'Arno contains only marine deposits. (Bertrand Geslin, *Ann. des Sci. Nat.*)

Agreeing in many respects with the freshwater aggregations in Val d'Arno, is a remarkable lacustrine deposit, of small extent (one fourth of a mile across), resting in a hollow of the new red sandstone formation, at Bielbecks, south of Market Weighton, in Yorkshire. The surface here is sandy and gravelly; for the sake of improving it the lacustrine marls below were excavated by the farmer, and in the lower part of the pit many bones and shells were found.

The excavation, being renewed under the direction of Mr. W. V. Harcourt, was continued to the bottom of the deposit, presenting in succession—

1. Black sand at the surface.
2. Yellow sand, with a few pebbles of quartz and sandstone, to the depth of - - - 3 feet.
3. Gravel, composed of chalk, pebbles, and sharp flints, to a depth of - - - 4½
4. Grey marl, indented by the gravel No. 3, and containing rolled pebbles of quartz, limestone and sandstone of the carboniferous system, with chalk and flint, reaching the depth of - - 10
5. Black marl, with minute pebbles of chalk, and very few flints; at the bottom a few fragments of a fine-grained calcareous sandstone, such as belongs to the neighbouring red marl.—Extreme depth - - - - 22½
6. Strong blue marl and some clay nodules.
   Flint gravel in marl.
   Strong blue marl.
   Flint gravel in marl.
7. Red marl, the basis of the whole deposit.

No bones, shells, or vegetable remains were found in Nos. 1, 2, 3. 6. or 7. In the grey marl, No. 4., bones and tusks and teeth of the elephant, a bone of the rhinoceros, and a part of the horn of a deer were found, but no vegetable reliquiæ, and no shells. In the black marl, No. 5, most of the bones, and all the shells and vegetable reliquiæ occurred. The whole collection contained—

Mammalia -	Elephas primigenius,	tusks, teeth, vertebræ, &c.
	Rhinoceros tichorhinus,	teeth, tibia, rib.
	Bos urus antiquus,	cranium, horns, teeth, bones of leg, &c.
	Stag of great size,	parts of horn and metatarsal.

	Horse of large size,	metatarsal and phalangal bones.
	Felis spelæa,	lower and upper jaw, and several leg bones.
	Wolf,	humerus, radius, and ulna of right side, right lower jaw, condyle of the other.
Birds -	- Duck,	ulna, clavicle, tibia.
Insects	- The green elytron of a species of chrysomela was recognised.	
Mollusca	- 13 species of land and freshwater shells, every one identical with species now living in the vicinity, were found mixed with bones of elephant, rhinoceros, viz. : —	

Helix nemoralis, caperata.	Planorbis complanatus, vortex, contortus, nitidus, spirorbis.
Pupa marginata.	Valvata cristata.
Succinea amphibia.	Pisidium amnicum.
Limnæa limosa, palustris.	

(*Geol. of Yorksh.* vol. i. 2d edit.)

Mr. Morris, in his Memoir on the Deposits containing Mammalia in the Valley of the Thames (*Magazine of Natural History,* Oct. 1838), presents a variety of information bearing on the contemporaneous races of mammalia and mollusca. The mammalian remains are of the 'diluvial' æra (elephant, rhinoceros, hippopotamus, horse ; ox ; deer, Irish elk ; vole, bear, lion, hyæna, — occurring at Brentford *, Wickham, Ilford *, Erith, Grays, Whitstable, Copford, Stutton, Harwich, Gravesend, Nine Elms, Lewisham, Kingslands. The shells found at Erith, Grays, Copford, Stutton and Ilford, are thus enumerated : —

Cyrena trigonula, at Ilford, Erith, Grays, and Stutton.

Cyclas obliqua, Stutton ; *C. cornea,* Stutton, Grays ; *C. pusilla,* Stutton.

Pisidium amnicum, Stutton.

Anodon cygneus, Grays, Stutton, Erith.

Unio pictorum, Grays, Erith, Ilford ; *new species* Erith (examined by Mr. G. B. Sowerby).

Succinea amphibia, Grays, Stutton ; *S. oblonga,* Ilford.

* Mr. Morris remarks that the shells which occur at these localities are of land and freshwater kinds, not marine, and agrees with the opinions of Mr. Charlesworth, that mammalian remains are more commonly associated with fluviatile and lacustrine, than marine and detrital deposits, a conclusion which is acquiring fresh importance every day. We have, in fact, preglacial and postglacial elephantine remains.

Helix hortensis, Ilford, Stutton, Grays; *H. lucida*, Stutton; *H. fusca*, Stutton; *H. rufescens*, Grays and Stutton; *H. paludosa*, Stutton; *H. hispida*, Erith, Stutton, Grays, Ilford; *H. trochiformis*, Stutton.

Carychium minimum, Stutton, Erith, Grays.

Pupa marginata, Stutton, Erith, Grays; *P. sexdentata*, Stutton, Erith, Grays.

Bulimus lubricus, Stutton.

Limax lubricus, Stutton.

Limnæa auricularia, Ilford, Stutton; *L. peregra*, Stutton, Copford, Ilford; *L. fossaria*, Stutton; *L. palustris*, Stutton, Grays.

Planorbis carinatus, Stutton, Erith, Grays; *P. corneus*, Ilford, Stutton, Erith; *P. vortex*, Stutton, Erith; *P. contortus*, Stutton; *P. imbricatus*, Stutton; *P. nitidus*, Stutton.

Paludina impura, Stutton, Grays, Erith, Ilford.

Valvata cristata, Stutton; *V. piscinalis*, Stutton, Copford; *V. antiqua*, Grays.

Ancylus lacustris, Stutton; *A. fluviatilis*, Stutton, Grays.

Thus, the former co-existence of extinct mammalia, and numerous mollusca not in the smallest degree different from recent species living in the same climates, which was first ascertained near Market Weighton, and confirmed by Mr. H. Strickland's researches in Worcestershire, is abundantly established by a large induction of instances.

Mr. Charlesworth, whose researches on the supracretaceous deposits of the eastern counties have led to other valuable results, presents, in the following general view of the beds which there occur above the chalk, a simple classification of the mammaliferous strata. (*Reports of the British Association*, for 1836, p. 85.)

Section I. Beds containing numerous remains of terrestrial mammalia: —

1. Superficial *gravel*, containing bones of land animals, probably washed out of stratified deposits.
2. Superficial *marine deposits* of clay, sand, &c., in which the shells, very few in number (10 or 15 species), may all be identified with such as are now existing. (Brick earth of the river Nar, Norfolk.)
3. *Fluviatile* and *lacustrine* deposits, containing a considerable number of land and freshwater

shells, with a small proportion of extinct shells; (mammalian remains in great abundance. (Ilford, Copford, and Grays, in Essex, Stutton in Suffolk.)

4. *Mammaliferous crag* of Norfolk and Suffolk, hitherto confounded with "red crag," containing about 80 species of shells; proportion of extinct species undecided. (Bramerton, near Norwich; Southwold and Thorpe in Suffolk.)

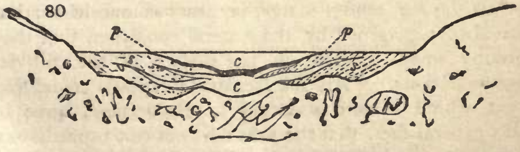
SECTION II. Beds in which few traces of terrestrial mammalia have yet been discovered:—

5. Red crag. (It contains mastodon, &c.)
6. Coralline crag.
7. London clay. (It contains quadrumana, &c.)
8. Plastic clay.

Modern Lacustrine Deposits.

Some small lakes are situated at this day, and many were in former times, so as to receive no considerable river, but many small runlets from the adjacent slopes. Under ordinary circumstances, the running streams throw into lakes only carbonate of lime, and other dissolved or suspended matters, which may be diffused with great equality in the water, and at length settle on the bottom in one or more layers. In times of abundant rain, coarser sediments are carried into such lakes from more numerous points of the margin, and thus the whole lake is filled toward the edges by narrow concentric sloping layers of sand and gravel (*s*), which are intermixed with layers of finer clay or marly substance (*c*), as in the diagram No. 80.; which also shows,

80



above several deposits of coarse and fine earthy materials, a single bed of peat (p), composed of the disintegrated portions of plants swept down from the land, or produced by vegetable growth on the spot. Above such a peat-layer it is usual to find in the middle parts of old lakes very fine marls, with or without shells, wholly unmixed with coarser sediments. This circumstance is commonly observed in many of the ancient lakes of Holderness, where, usually, the middle part of the lake-bed contains little or no coarse sand or gravel.

In these fine marls tubular passages, left by the roots of aquatic plants, frequently appear; and shells of fresh-water (or land) species commonly occur. Heads and horns, and sometimes entire skeletons of the red deer, the Irish elk, beaver, &c., are buried in the marls or peat, under circumstances which indicate in some cases the drifting of their dead bodies by water, and in others require the supposition that the animals had entered the lake through choice or fear, and been drowned and covered by sediments.

Certain fine layers, in freshwater lakes of Denmark, have been found by Dr. Forchhammer to be composed of the siliceous matter arising from the disintegration of the epidermis of some fresh water plants. Seeds of Chara occur in others; and it is probable that the calcareous substance of this plant has contributed not a little to the mass of *friable marls which lie in many lakes.*

On the coasts of Yorkshire and Lincolnshire, lacustrine deposits occur at many points, and present a considerable variety of circumstances as to level above or below the sea, sandy, marly, or peaty composition; but are always governed by the general condition, that they occupy small hollows on the surface of the diluvial accumulations. "All the lacustrine deposits containing peat, which I have inspected in Holderness, agree in this general fact, that the peat does not rest immediately upon the diluvial formation beneath, but is separated from it by at least one layer of sediment, which is seldom without shells. The peat is very generally confined to a single layer, and shells are seldom found above it. Supposing that all the varieties which I have witnessed in different places existed together, the section would be nearly in the following general terms: —

*1. Clay, generally of a blue colour and fine texture.
*2. Peat, with various roots and plants, and, in large deposits, containing abundance of trees; nuts, horns of deer, bones of oxen, &c.
3. Clay of different colours, with freshwater limnææ.
4. Peat, as above.
*5. Clay, with freshwater cyclades, &c., and blue phosphate of iron.
6. Shaly curled bituminous clay.
7. Sandy coarse laminated clay, filling hollows in the diluvial formation.

Of these the most constant beds appear to be Nos. 1, 2. and 5.; and in general these constitute the whole deposit. The peat varies from 5 feet in thickness to less than so many inches. In a few instances, the lower clay, No. 5, contains no shells: the species which so occur are not always the same: Cyclades and small Paludinæ are the most plentiful: Anodons occur at Skipsea and Owthorn, but I did not find them elsewhere. Skeletons, and detached horns of the Irish elk (Cervus euryceros), red deer, and fallow deer, occur in it at several points." (*Geol. of Yorkshire*, vol. i.)

A deposit of similar origin in Berwickshire, full of limnæana and planorbes, envelops horns of the red deer and bones of the beaver. At Silverdale, near Burton in Kendal, and at other points round the bay o Morecambe, deposits from fresh water, probably of equal antiquity, occur at such levels that the tide might easily flow over them. They are usually covered by peat at the surface, and composed of shell marls in considerable quantity, the shells belonging to Limnæa, Planorbis, Cyclas, Pisidium, &c., and apparently identical with existing species. Occasionally the bones of the great Irish elk occur in these marls (a fine pair is to be seen over a doorway in Garstang); and from them Lee states the head of hippopotamus, figured in the Natural History of Lancashire, to have been derived.

To this period we may also refer the lacustrine and peat deposits of the Isle of Man, and Ireland, which have yielded the fine skeletons of the Irish elk, now standing in the museums of Edinburgh and Dublin. The specimen in the Royal Dublin Society's collection was obtained by archdeacon Maunsell, at Rathcannon, near Limerick, in shelly marl, 1½ to 2½ feet thick under peat 1 foot thick, and above blue clay 12 feet thick or more. According to Mr. Griffith, it is in these white shelly marls, under peat, that all the skeletons of the Irish elk have been found, which agrees with what has been observed in England. (*Outline of the Geology of Ireland*, 1838.)

"At Milk Pond in New Jersey, countless myriads of bleached shells of the families limnæana and peristomiana, analogous to species now living in the adjoining waters, line and form the shores of the whole circumference of the lake to the length and depth of many fathoms. Thousands of tons of these small species, in a state of perfect whiteness, might be used for agricultural purposes. In one case, a perforation was made 10 or 12 feet deep, and did not pass through the mass. It forms the whole basin of the lake, and may at some future time become a tufaceous lacustrine deposit." (Lea, *Contrib. to Geol.* p. 225.)

Mr. Lyell's description of the deposits which are still proceeding in Bakie Loch, Forfarshire, offers an excellent type of comparison for analogous deposits of older date. The sediments in this lake are principally two beds of calcareous shelly marls, separated by a loose sandy deposit, covered by a layer of peat with trees, and resting on fine sand and detritus. The calcareous matter is supplied by springs, and in general is of a soft friable nature; but near the springs it is solidified, and receives the title of "rock marl." It is principally to the vital functions of limnææ, cyclades, and charæ, that the separation of the calcareous matter from the water of the lake is owing; and though, in some parts of the deposit, all trace of their individual forms is lost, (as in certain coral reefs the organic structure is obliterated by the decomposition and recondensation of the mass), there is reason to think the greater part of the marls is really a congeries of organic exuviæ. Horns of the stag lie in the marls. There are no unionidæ among the shells.

Subterranean and Submarine Forests.

Buried Trees on the Course of a River.

It appears that sometimes the violence of river floods was so great as to sweep down to the tide-line abundance of land plants, which, covered by sediment, constitute by their accumulation one kind of buried or subterranean forest. A very interesting case of this kind was exhibited some years ago, by the deep cutting of a canal connected with the Aire and Calder navigation, near Ferrybridge. At a depth of 12 feet from the surface of the fine alluvial sediment, here occupying the broad valley of the Aire, a quantity of hazel-bushes, roots, and nuts, with some mosses, freshwater shells (Limnæa, Planorbis, &c.), and bones of the stag were met with. In some part of the superjacent sediments, an English coin was found, and oars of a boat were dug up. Where a little water entered this peaty and shelly deposit, from the adjacent upper magnesian limestone, it produced in the wood a singular petrification; for the external bark and wood were unchanged, but the internal parts of the wood were converted to carbonate of lime, in which the vegetable structure was perfectly preserved. In like manner, some of the nuts were altered; the shell and the membranes lining it were unchanged; but the kernel was converted to carbonate of lime, *not crystallised,* but retaining the peculiar texture of the recent fruit.

What renders this curious case of *elective molecular attraction* the more decisive, is the fact that, in the same deposit, sulphuret of iron was found, but only *on the outside* of wood; and, from the whole we learn that, just as in the chambers of ancient ammonites, and cells of the bones of saurians, the carbonate of lime has passed through shell, membrane, and bone, and penetrated precisely to those spots where it might seem most difficult for it to arrive, so, in the comparatively modern nuts and woods, the same substance has been similarly transferred to the interior parts, through solid matter; while sulphuret of iron in both cases remains on the outside.

In this particular case, no reasonable doubt can exist (we conceive) that the peaty deposit, full of land mosses, hazel-bushes, and freshwater shells, was water-moved, and covered up by fine sediments from the river and the tide. In some of the old *lakes* of Holderness, the same mechanical explanation appears applicable: an example has been furnished (Waghen in Holderness), which shows on the same spot, first, the accumulation of violently agitated water ("diluvium"); then a deposit of fine clay, and several layers of peat and trees of different kinds; and over all, the stumps of pines (Scotch fir), which seem to be in their place and attitude of growth.

On Chat Moss, near Manchester, and in other situations, the stumps of oak trees appear in the attitude of growth, though the *proof* of the trees having grown there is seldom completed by the actual tracing of the roots *laterally*, or, what is still more important, *downwards* in the clay. Dr. W. Smith has observed, in the deposits of trees in East Norfolk, differences according to the soil; birches and alders on sand, and oak trees on an argillaceous bed.

In England, Wales, and Scotland, deposits of this nature, full of trees and vegetable reliquiæ of different kinds, abound much more on the sea coast, and in alluvial land which has been deposited within the ancient sea boundary, than elsewhere. Occasionally, it is true, amidst the mountains of Westmoreland (as in a small hollow between Kirkby Lonsdale and Kendal) and Scotland (as at the head of Glencoe), trees, rooted or prostrate, occur mixed with peat; but it is on the shores, or in the midst of the alluvial plains of Yorkshire, Lincolnshire, Cambridgeshire, West and East Norfolk, Cornwall, Somersetshire, Swansea, Cheshire, Lancashire, the mouths of the Clyde, Forth, and Tay, the shores of the Orkneys and Hebrides, that the most abundant of these buried forests occur. This general fact justifies the title of *Submarine Forests*, commonly applied to them, and is of great importance in reasoning on the circumstances of their accumulation. On the contrary, the greater part of the Irish bogs are inland accumulations; but they occupy the lower plains of the country, and are often margined by gravel banks, and abound on the line of the Shannon, which is a stream of very little declivity.

The trees contained in these deposits are identical with those now growing in the vicinity, hazel branches and nuts being very common; with them are occasionally found fluviatile or lacustrine shells, and bones of deer and other land animals; but, as far as we know, no marine mollusca, and seldom marine remains of any kind. The level of the buried trees is seldom above, but generally below, the high-water line, and often level with, or not unfrequently many feet, or even yards, below, low-water. On the sides of the Humber, below Hull, submarine peat and trees are found at various depths below low water; at the mouth of the Tay, level with it; at Swansea and Owthorne, sloping beneath it; at Sutton, near Alford, on the Lincolnshire coast, visible only at the lowest ebb-tides.

As De Luc suggests, with regard to the layers of peat resting on clay at Rotterdam (*Hist. de la Terre et de l'Homme*, tom. v. p. 325.), we may believe the deep-buried trees and peat of the sides of the Humber to have been *drifted;* but this is not the explanation generally proposed by observers, who appear almost without exception impressed with the belief that the trees grew on the spots where now they lie prostrate, and often buried beneath lacustrine or fluviatile (seldom marine) sediments.

To account for their occurrence, at levels and under circumstances which now render the growth of trees almost impossible, it is sometimes supposed that the waste of the coast has opened to the sea some secluded valley of peat, which, originally full of moisture, like a sponge, was raised thereby above the tide-level, but, on the loss of its seaward barrier, was drained, and sunk considerably. (Dr. Fleming, in the *Quarterly Journal of Science,* 1830.) But in most cases a real subsidence of the land is appealed to. (Dr. J. Correa de Serra, in *Phil. Trans.* 1799.)

The evidence in favour of the opinion that the trees really grew on the spots where now they appear has generally been thought satisfactory by geological writers; it is, however, not always so exact and complete as might be desired, because the circumstances which accompany the submarine forests have seldom been carefully inquired into with this object in view. Speaking of the deposits on the shores of the Frith of Tay, Dr Fleming observes, that "the upper portion of the clay, on which the vegetable accumulation immediately rests, is *penetrated by numerous roots,* which are changed into peat and sometimes into iron pyrites." Stumps of trees, with roots attached, are observed on the surface of the peat. Leaves, stems, and roots of equisetaceæ, gramineæ, and cyperaceæ, with roots, leaves, and branches of birch, hazel, and probably alder, constitute the mass of the deposit. Hazel nuts without kernel abound. All these remains are much flattened where they lie horizontally, but the stems which remain erect retain their cylindrical figure. This is exactly similar to the condition of stems of trees in a coal district.

One of the most interesting deposits of peaty matter is that associated with *drifted tin ore,* on the coast of Cornwall. The deposit of Sandrycock, between the parishes of St. Austle and St. Blazy, is described by Mr. P. Rashleigh (*Geol. Trans. of Cornwall,* vol. ii. p. 281.) as occupying a vale, which has received drifts from the sea, as well as from the country above. The series of beds is thus noticed: —

	ft.	in.
1. Vegetable mould, about - - - -	0	3
2. Gravel and micaceous sand, mixed with fine loam, in alternate beds of various depths, making together - - - - -	8	3
3. Light-coloured clay, with a little mica, and a few roots of vegetables nearly decayed - -	5	3
4. Black peat - - - - -	4	1
5. Light coloured clay - - - -	1	4
6. Stiff clay of a light brown colour, with some decayed roots of vegetables. The clay was spotted with light blue (phosphate of iron) - -	3	10
7. Sea sand and clay mixed . - -	3	0
8. Very fine sea sand, together with mica and small fragments of shells and killas - - -	4	0
9. Coarser sand without shells - - -	6	0
10. A solid black fen, with a few remains of vegetables, in which are round globules of the size of middling shot, but not harder than the fen. This substance is not made use of as fuel -	2	10
11. *Tin ground,* and loose stones of all sorts. This bed varies in thickness from 1 ft. to -	6	0
12. Killas, the general base of the deposit.		

At Mount's Bay (Dr. Boase, in *Trans. Geol. Soc. Cornwall*), the vegetable deposit is covered, on the sea coast, by a thick bed of shingles, and inland, appears beneath a marsh. Elytra of insects appear in this deposit, very little changed from their pristine beauty.

De Luc paid great attention to peat deposits and buried forests in all situations. In his observations on Holland he makes frequent mention of the low level of the peat and silt deposits, attributing this circumstance to a subsidence of those materials in the course of their desiccation. From M. Van Swinden he learned that there were lakes in Friesland, which had once been woods. "Le Fljuessen Meer, par exemple, grand lac au N. E. de Staveren, étoit encore un bois en 489; et ce lac, ne pourroit être desséché aujourd'hui que par artifice." The soil of Holland, which has been longer enclosed in banks than Friesland, is on a lower level. The same explanation applies to the fact, well known near Lynn, that the land which has been regained since the Roman sea banks were made is on a higher level, and of greater value, than that which was enclosed by the Romans; and outside of "Marshland," as this tract is called, the new foreshores are sometimes *still higher*.

For the following interesting fact we are also indebted to De Luc: —

"Près de la Scanie, dans la mer Baltique, est une isle nommée *Bornholm*, environnée de collines de sable, dont le milieu est une vaste *Tourbière*, sous laquelle on trouve quantité de sapins, couchés de la circonférence au centre. Cette dernière circonstance, pour le dire en passant, prouve toujours mieux que ces arbres n'ont pas été abattus par des inondations, mais par les vents. Ici, plongeant du haut des collines, et tout le tour en differens tems, les vents ont renversé ces arbres quand la *tourbe* a été profonde et molle, et les ont ainsi couchés de la circonférence vers le centre." (*Hist. de la Terre*, Partie X. Lettre cxxvi. tom. v. p. 222.)

He applies this fact to explain the origin of coal from peat, and enters into a short explanation of the mode by which he conceives the submerged peat was covered by the argillaceous schistus of its roof, enveloping the plants then growing on the peat; remarking that both elevations and depressions of land happened before the final desiccation of our continents, and noticing the differences of the ancient and living flora of the peat moors.

Turf Moors.

Submarine and subterranean forests are almost universally associated with peat, or turf, as it is called in the north of England, and indeed, generally, they constitute a considerable portion of the vegetable mass. There are, however, peat bogs in which no timber lies buried; and many of these are daily and hourly augmenting their area, and increasing their depth, by the growth of living, and the accumulation of dead, plants. Though the gigantic "peat plant," as described by some writers, is an imaginary creation, *sphagnum palustre* and other humble mosses appear to deserve the epithet, and heather is a very common accompaniment. To an antiseptic property, imparted by this latter plant, De Luc was disposed to ascribe the conservation and accumulation of the various vegetable substances which occur in peat.

There are few shallow lakes in the interior of England, and especially in the sandy tracts, like Cheshire and Nottinghamshire, which are not, in some part or other, encroached on by the growth of peat. Preceded by reeds, this substance slowly advances over the sandy or pebbly bed, and changes to damp and shaking meadows the surface of the upper end of the lake. The upper end of Derwentwater, Ulswater, and many of the mountain lakes in Wales, display this growth of peat completely; and in many of the wide bogs of Ireland, the Isle of Man, and Arran, we see the process finished, and the lakes wholly obliterated in a spongy carbonaceous mass. In a similar way, many of the valleys without lakes, and many of the elevated slopes and summits of hills, especially on gritstone or granite surfaces, both in the south of England (Dartmoor), among the Yorkshire hills (Watercrag, Great Whernside), and the Cumbrian mountains (between Skiddaw and Saddleback), are covered with great depths of peat, in which trees are never seen. Similar facts appear among the Grampians, on the mountains near Enniskillen, and in other parts of Ireland; and these extensive tracts of "moor," as De Luc calls the peat deposits in the north of Germany, are supposed to be no where so abundant as in northern latitudes.

The bogs of Ireland lie principally in the central parts, on the wide plains of mountain limestone, and are supposed to cover one-tenth of the surface of the island. The thickness of the peat varies from 12 to above 40 feet; the upper layers being very fibrous, and showing clearly the structure of the component plants; the lowest, a close dense mass, much resembling coal, and breaking with conchoidal fracture.

Most of the Irish peat bogs contain trees, which in some cases lie at the bottom; and it may be thought that the whole deposit is little else than the accumulated ruins of a long succession of forests; in other cases the vegetable mass, whether thus accumulated or aggregated by drifting, has served as the basis of a new race of trees, whose roots remain at the surface. And it is observed, in the "Reports" on the bogs of Ireland, that in that country it is common to find trees, in the place and attitude of growth, rooted on peat seven feet thick. This is especially the case with fir trees (so at Waghen, in Yorkshire), but oaks are commonly found to rest on the gravelly basis of the bog. Shelly marls frequently lie under the peat, and indicate that, in such cases, the origin of the bog is to be ascribed to the same process which is constantly going on to extinguish some modern lakes. This is the view adopted by the ordnance surveyors, in their Report on the County of Londonderry.

Antiquity of Subterranean Forests.

Closely connected with the determination of the question whether the trees of the "submarine forests" grew where now they lie enveloped in peat, are facts ascertained regarding the antiquity of certain of these deposits. De Luc, who looked on phenomena of this nature with great interest, on account of their important bearing on two capital points to which his mind was continually turning, viz. the origin of coal, and the antiquity of our continents,—notices, a few leagues from Winsen (near Hamburg), the occurrence of four or five inches of vegetable earth (terre végétable) above ancient burial mounds, composed of heaps of stones, and inclosing frequently an urn of burnt bones. Observations nearly similar may be easily made on the heathy and peaty moors of the elevated parts of the north of England, where tumuli and ancient roads and causeways are nearly concealed by the growth of vegetables and aggregation of sands.

But the accumulation of peat from living plants is in some places so rapid, that it seems endowed with an inexhaustible vitality, and may be cut like a copsewood every fourteen years. And in countries like Hatfield Chace, which are one wide turf moor, the occurrence of Roman coins, and axes yet fixed in the wood, appear to prove at once the fact that the trees grew on the spot, and fix the historic date of their destruction.

De Luc mentions the discovery of a medal of Gordian 30 feet deep in peat at Groningen. Besides other proofs of the modern origin of this substance, near Bremervörde, a small hill of "hard land" or "geest," is stated to be overgrown with peat, and its title "Isleberg" shows the modern date of this overgrowth. (*Lettres sur l'Histoire de la Terre et de l'Homme,* tom. v. p. 264.)

"De Luc ascertained that the very site of the aboriginal forests of Hercinia, Semana, Ardennes, and several others, are now occupied by mosses and fens; and a great part of these changes has, with much probability, been attributed to the strict orders given by Severus and other emperors to destroy all the wood in the conquered provinces." (Lyell, *Princip.* book iii. ch. xiii.)

One of the most valuable of all the descriptions of subterranean forests is that of Hatfield Chace in Yorkshire, by the Rev. A. De la Pryme (1701). Of 180,000 acres here, constituting the largest chace of red deer in England which belonged to Charles II., about half was yearly drowned by vast quantities of water. Sir Cornelius Vermuiden drained it, at a cost of 400,000*l.*, cutting amongst other great works a new channel for the tide river Don, which is now called

Dutch River, one of the old channels, which entered the Aire, being now nearly filled up. In the beds of the rivers, below the marshland, and all round to the highlands of Lincolnshire and Yorkshire, are found "vast multitudes of the roots and trunks of trees of all sizes, great and small, and of most of the sorts that this island either formerly did, or that at present it does, produce; as firs, oaks, birch, beech, yew, thorn, willow, ash, &c.; *the roots of all or most of which stand in the soil in their natural position as thick as ever they could grow, as the trunks of most of them lie by their proper roots.* Most of the large trees lie along about a yard from their roots (*to which they evidently belonged, both by their situation and the sameness of the wood*), with their tops commonly north-east; though, indeed, the smaller trees lie almost every way across the former, some over and others under them." A third part of the trees were of the fir tribe (some 30 yards long and more), and in such condition as to be sold for masts and keels for ships; oak, black as ebony, abounded, 35 yards and more long, and useful in carpentry; ash trees were the only ones found decayed. "Some of the fir trees, after they were fallen, have shot up large branches from their sides, which have grown up to the height and bulk of considerable trees." (Hutton's *Abridgment, Phil. Trans.* vol. xxii.)

Many of the trees, and especially the fir trees, have been burnt, sometimes quite through; others chopped, squared, bored through, or split, with large wooden wedges and stones in them, and broken axe-heads, somewhat like sacrificing axes in shape, and this at depths, and under circumstances, which exclude all supposition of their being touched since the destruction of the forest. "Near a large root in the parish of Hatfield were found eight or nine coins of some of the Roman emperors, but exceedingly defaced with time; and it is very observable, that, on the confines of this low country, between Burningham and Brumley in Lincolnshire, are several great hills of loose sand, under which, as they are yearly worn and blown away, are discovered many roots of large firs, with the marks of the axe as fresh upon them as if they had been cut down only a few weeks." (Hutton's *Abridgment*, vol. xxii.)

Hazle nuts, and acorns, and fir cones, in great abundance, lie heaped together at the bottom of the soil; and "at the bottom of a new river or drain (almost 100 yards wide and 4 or 5 miles long), were found old trees squared and cut, rails, stoops (gateposts), bars, old links of chains, horse-heads, an old axe somewhat like a battle-axe, and two or three coins of Vespasian. But what is more remarkable, is that *the very ground at the bottom of the river was found in some places to lie in ridges and furrows, thereby showing that it had been ploughed and tilled in former days.*" (Ibid.)

Mr. De la Pryme was informed by Mr. E. Canby, that he had found an oak tree which was 4 yards across at the base, 3½ yards in the middle, and 2 yards across the top; and the length of this fragment (the top was gone) was 40 yards. The same person found a fir tree 36 yards long, and estimated it to be deficient 15 yards = 51 yards or 153 feet. (The highest fir tree which has fallen under our observation in England, is a spruce fir near Fountain's Abbey, stated to be 118 feet above the grass.)

The roots of the fir trees have been observed to be in the sand, and those of the oak trees in clay.

"About 50 years ago," says Mr. De la Pryme, "at the very bottom of a turf pit, there was found a man, lying at his length, with his head upon his arm, as in a common posture of sleep, whose skin being tanned, as it were, by the moor water, preserved his shape entire; but within, his flesh and most of his bones were consumed."

Another case of this nature was brought under the examination of the author of this volume, by Mr. W. Casson, of Thorn, who forwarded to the Yorkshire Museum (1831), the head of a fallow deer, found in the peat near that place, in a singular condition. The bones and teeth were, in fact, changed to leather; the hardening earth having been dissolved in the sulphuric acid, which is of ordinary occurrence in the peat of Yorkshire, and the residuary gelatine changed to leather by the tannin.

The prostration of the trees towards the north-east has been noticed by Verstegan and De Luc, in the morasses of the Netherlands and Germany. De Luc, speaking of the abundance of trees lying below the peat of the country near Bremervörde, attributes their direction from S.W. to N.E. to the prevalent winds and rains from the S.W.; he also notices the chopping and burning of the trees. (*Lettres*, tom. v.)

The conclusion of Mr. De la Pryme, "that the Romans were the destroyers of all the great woods and forests which we now find underground in the bottom of moors and bogs," has been generally adopted by geologists; and, with regard to districts where the Roman sway was impotent or unknown, as Wales, the Isle of Man, and Ireland, the destruction of many forests is charged on later conquerors.

If, from the contemplation of evidence concerning the historic date of subterranean forests furnished by the coins of Rome, and ruder works of earlier people, we turn to the monuments of nature, the remains of men and quadrupeds, which occasionally present themselves in drains and other excavations, we find the impression, that the overthrow of the forests took place in comparatively modern geological times, materially strengthened. For, while the bodies of men and women, which have been found in Solway Moss, in the bogs of Ireland, and other parts, agree with the evidence of coins, axes, and canoes, the bones of quadrupeds belong, almost in every instance, to existing species, as the red and fallow deer, wolf, beaver, horse, ox, and sheep; the insects and mollusca, and all the trees and plants, are of types yet living in the same vicinity.

Yet, to this general rule are, at least, two seeming exceptions. The head of a hippopotamus is figured by Lee, in his History of Lancashire, and noticed as found under the peat of Lancashire; works of human art being also mentioned; and bones and antlers of the great extinct elk of Ireland occur in many of the peaty and marly deposits of Ireland, the Isle of Man, Lancashire, and Yorkshire.

Another example of peat deposits connected with shell marls, which contain quadrupeds of the same races as those usually supposed to characterise the diluvial deposits, occurs at Wittgendorf, near Sprottau (Silesia). Here, according to Meyer (*Palæologica*), below a thin bed of drifted sand and pebbles, in the lower parts of a peat deposit, 6 to 8 feet thick, and also in marls below, lie bones of Elephas primigenius, oxen, deer, and fish, with cyclostomæ. In these cases, the bones and shells show no sign of abrasion.

If we turn to America, and take as an example the circumstances which accompany the bones of the great mastodon, the inference previously adopted as to the age of the peat deposits is confirmed; for these certainly date from an epoch subsequent to the dispersion of diluvial detritus. But, as regards the animal remains, we learn that a tooth of the mastodon occurred at Fort M'Henry, near Baltimore, below "diluvium;" and it is well known that, at Big Bone Lick and in New Jersey, and elsewhere, nearly complete skeletons of Mastodon giganteus occur in peat and shelly marls of comparatively recent date, along with extinct and living species of oxen and deer.

"From all the facts before me," observes Professor Rogers, in his Report to the British Association, 1834, on the geology of North America, "I have little hesitation in giving my opinion, that the extinct gigantic animals of this continent, the mastodon, elephant, megalonyx, megatherium, fossil bos, and fossil cervus, lived down to a comparatively recent period, and that some of them were in existence so long ago as the era anterior to that which covered the greater part of this continent with diluvium."

The conclusion here presented may very probably, or rather certainly, be extended to the Irish elk, of which the perfect specimens appear to be of comparatively modern date; but various fragments, apparently of the same species, have been detected in the ossiferous caves and gravel of northern regions, which contain the mammoth and rhinoceros. It will depend upon farther research, whether this conclusion may be extended to the extinct elephant, hippopotamus, and rhinoceros, and to the living stag, ox, horse, and wolf. Concerning these latter animals, we can only affirm, that it has been found impossible to distinguish, by any constant marks, the specimens found in ancient caverns and gravel beds, from those now living in the same regions.

CHAP. VII.

UNSTRATIFIED ROCKS IN THE CRUST OF THE EARTH.

General Remarks.

In a former part of this work* a general view is given of the reasons which have guided modern geologists in ascribing to a large class of rocks in the crust of the earth an original state of igneous fusion; and in connection with each system of strata some notice is taken of the distribution and characteristic phenomena of the igneous rocks locally associated therewith. We must now take up the subject in a comprehensive point of view, and elucidate its bearings on the general problem of the effects of heat in the crust of the globe. We must unite into one contemplation the history of the whole series of igneous rocks of every age, from the supposed "fundamental granite" to the volcanic mounds, heaped up under daily observation. And in this review care must be taken, both to combine and to analyse the knowledge of igneous effects, so as to obtain from the whole investigation trustworthy conclusions regarding the true condition of the globe, in respect of heat, at and below the surface, in successive geological periods.

Igneous Origin. — In asserting, concerning granite, basalt, porphyry, and other rocks, that they are of igneous origin, we must be careful to explain that it is not meant to affirm, that the materials of which these rocks consist have not existed together in any other combination, or been subject to other conditions previously.

* See Vol. I. p. 45.

Fusion obliterates all or most of the marks of earlier states of material arrangement, and it is only in a few cases that direct or indirect evidence remains, by which to form a correct judgment respecting them. Granite *may* have been derived from the fusion of previously formed strata, a mode of origin confidently ascribed to certain ancient porphyritic rocks, and probable with regard to some modern lava. The origin of all natural phenomena is obscure; and with regard to the rocks above named, and others like them, all that it is now necessary to admit, is that, through whatever previous conditions the matter of which they consist has passed, their last combination, in which they now appear, has been caused by the agency of heat.

Geological Age.—Heat, though a simple cause, is productive of most complicated effects; not only because of the unequal action of different degrees of heat, or the various habitudes of the substances operated on, taken singly or in combination, but because extraneous circumstances, such as pressure, the passage of electrical currents, &c., affect the condition of the fused mass, and modify the aspect and arrangement of the solidified products. The mere antiquity of an igneous rock is a circumstance absolutely inefficient in accounting for any other of its characters than the degree of superficial waste, or internal change by particular agencies; and therefore an inquiry into the composition and structure of such rocks must in the first instance include the whole series of igneous products, if we wish to determine, in the first place, the conditions to which particular phenomena are due, and, finally, to obtain a correct general history of the change of these conditions in the order of geological time.

Composition.—Reduced to their last molecules, all igneous rocks appear to be oxides of various metallic and metalloid bodies, oxygen constituting about one half of their weight; silicium, aluminum, magnesium, calcium, potassium, sodium, iron, &c., are the most prevalent elementary bases, of even the most dissimilar rocks.

Silica, or silicium combined with oxygen, is found abundantly in perhaps every igneous rock, and very commonly is combined in definite atomic proportions with lime, alumina, &c., so as to form a peculiar class of compounds, called silicates, bisilicates, and trisilicates, according to the atomic proportion of silica in the mineral. So general is this fact that, considering the easy fusion of most earthy substances in contact with silica, and the well known fact that in most of the igneous rocks some superabundant silica remains (in the state of quartz), we may contemplate the whole mass of these rocks as having existed in the state of a siliceous glass, from which, according to the admixture of other elements, silicates, bisilicates, &c., would be formed by crystallisation; or, according to the rate of cooling, pressure, and other circumstances, earthy aggregates, compact stones, or glassy products, result.

According to this view, the differences between some of the most remarkable igneous rocks are merely in the degrees of arrangement to which their particles have been subjected. As lava, obsidian, and pumice, are merely three states of the same volcanic product, so probably the granitic, porphyritic, and homogeneous rocks, generated by heat in ancient times, have derived their characteristic structures from the conditions of their solidification. On this subject it is satisfactory to refer to the capital experiments of Mr. Gregory Watt (*Phil. Trans.* 1804), which are among the most interesting and instructive on record, and have been repeated by other observers with like success.

Mr. Watt's experiments were made on the amorphous basalt of Rowley, in Staffordshire, a fusible, fine-grained, confusedly crystalline stone, of dark colour, and opaque. It affects the magnetic needle, and has a specific gravity of 2·868.

Seven hundred weight of this rock was placed in a reverberatory furnace, on the elevated part of the interior, between the fire and the chimney, from whence, as it melted, it flowed into the deeper part, where the melted iron is usually collected. When the whole was melted, it formed a liquid glass, rather tenacious. From this a large ladleful was taken; which being allowed to cool, retained the characters of perfect glass. The fire was maintained throughout, with gradual diminution, for more than six hours, after which time the draught of the chimney was intercepted; the surface of the glass was covered with heated sand, and the furnace was filled with coals, which were consumed very slowly. By these precautions the heat was so slowly conducted away, that it was eight days before the mass in the furnace was sufficiently cool to be extracted, and even then it retained considerable warmth.

The form of the mass, being derived from the bottom of the furnace, was considerably irregular, approaching to the shape of a wedge, whose lower angles were rounded. It was nearly three feet and a half long, two feet and a half wide, about four inches thick at one end, and above eighteen inches at the other. From this diversity of thickness, and from the unequal action of the heat of the furnace, too great an irregularity had prevailed in the refrigeration of the glass to permit the attainment of a homogeneous texture. These circumstances might probably have been counteracted by better devised precautions; but the inequality of the product is not to be regretted, since it disclosed some very singular peculiarities in the arrangement of bodies passing from a vitreous to a stony state, which might have remained unobserved, if the desired homogenity of the result had been obtained.

1. This substance is easily fused into glass, with few air-bubbles; it then possesses an undulated conchoidal fracture, is black and opaque, except in thin fragments, and harder than felspar. Its sp. gr. is 2·743, and it has *no action* on the magnetic needle.

2. The tendency towards arrangement, in the particles of the fluid glass, is first developed by the formation of

minute globules, which are generally nearly spherical, but sometimes elongated, and which are thickly disseminated through the mass. The colour of these globules is considerably lighter than that of the glass; they are commonly greyish brown, sometimes inclining to chocolate-brown; and when they have been formed near the interior surface of the cavities in the glass, they project, and resemble a cluster of small seeds. Their diameter rarely exceeds a line, and seldom attains that size, as in general they are so near to one another that their surfaces touch before they can acquire considerable magnitude. In the process of cooling, they adapt their form to their confined situation, fill up every interstice, and finally present a homogeneous body wholly unlike glass, and equally unlike the parent basalt. When the union of the little globules has been imperfectly effected, the fracture of the mass indicates its structure by numerous minute conchoidal surfaces, which display the form of each globule.

But, if the arrangement has extended a little farther, all these subdivisions are entirely lost; the mass becomes perfectly compact; has an even or a flat conchoidal fracture; is nearly of the same hardness as the glass; is commonly of a chocolate colour, graduating into a brownish black; and the intensity of the colour increases in proportion to the degree to which the arrangement has extended. Its aspect is rather greasy; and it much resembles some varieties of jasper in the compactness of its texture, and in its opacity. Its magnetic action is extremebly *feeble*. Sp. gr. 2·938.

3. If the mass were now rapidly cooled, it is obvious that the result would be the substance just described; but if the temperature adapted to the further arrangement of its particles be continued, another change is immediately commenced, by the progress of which it acquires a more stony texture, and much greater tenacity, and its colour deepens as these changes advance, till it becomes absolutely black. Sometimes this alteration is effected by a gradual transition, the limits of

which cannot be assigned, but more generally by the formation of secondary spheroids in the heart of the compact jaspideous substance. These spheroids differ essentially from those first described; the centres of their formation are more remote from each other, and their magnitude is proportionably greater, sometimes extending to a diameter of two inches, and seeming only to be limited by contact with the peripheries of other spheroids. They are radiated, with distinct fibres: sometimes the fibres resemble those of brown hæmatites, and sometimes they are fasciculated irregularly, so as to be very similar in appearance to the argillaceous iron ores rendered prismatic by torrefaction. They are generally well defined, and easily separable from the mass they are engaged in; and often the fibres divide at equal distances from the centre, so as to detach portions of the spheroid in concentric coats. The transverse fracture of the fibres is compact and fine-grained; the colour black; and the hardness somewhat inferior to that of the basaltic glass. When two of the spheroids come into contact by mutual enlargement, no intermixture of their fibres seems to take place: they appear equally impenetrable, and in consequence both are compressed; their limits are defined by a plane, at which a separation readily takes place, and each of the sides is invested with a rusty colour. When several spheroids come in contact on the same level, they are formed by mutual pressure into pretty regular prisms, whose division is perfectly defined; and when a spheroid is surrounded on all sides by others, it is compressed into an irregular polyhedron.

4. The transition from this fibrous state to a different arrangement seems to be very rapid; for the centre of most of the spheroids becomes compact before they attain the diameter of half an inch. As the fibrous structure propagates itself by radiating into the unarranged mass, the compact nucleus which supplies its place gradually extends till it finally attains the limits of the spheroids; and the same arrangement pervades the matter compre-

hended between them. The mass has now assumed a compact stony texture, and possesses great tenacity. Its hardness is somewhat inferior to that of the glass from which it was formed. Its action on the magnetic needle is very considerable. Sp. grav. 2·938. Its colour is black, inclining to steel grey; it is absolutely opaque, and only reflects light from a few minute points. Though the divisions between the spheroids are rendered imperceptible to the eye, they are not obliterated, and their rusty surfaces are often disclosed by an attempt to fracture the mass.

5. A continuation of the temperature favourable to arrangement speedily induces another change. The texture of the mass becomes more granular, its colour rather more grey, and the brilliant points larger and more numerous: nor is it long before these brilliant molecules arrange themselves into regular forms; and, finally, the whole mass becomes pervaded by thin crystalline laminæ, which intersect it in every direction, and form projecting crystals in the cavities. The hardness of the basis seems to continue nearly the same; but the aggregate action of the basis and of the imbedded crystals on the magnetic needle is prodigiously increased. The substance now appears to possess some polarity, and minute fragments of it are suspended by a magnet. Its specific gravity is somewhat increased, as it is now 2·949. The crystals contained in it, when examined by a microscope, appear to be fasciculi of slender prisms, nearly rectangular, terminated by planes perpendicular to the axis: they are extremely brilliant; their colour is greenish black; they are harder than glass, and fusible at the blowpipe; they are suspended by the action of a magnet. They are arranged nearly side by side, but not accumulated in thickness, so that they present the appearance of broad thin laminæ; they cross one another at all angles, but always on nearly the same plane; and the lamina thus formed is often three or four lines long, and from a line to a line and a half broad, but always extremely thin.

The cavities which existed in the glass are not obliterated during the subsequent processes, though changed on the surfaces.

All these steps in this remarkable experiment may be compared with parallel instances in the products of volcanos.

Thus, from homogeneous obsidian we pass to that variety of it which envelopes small globular concretions; and these, by increasing in number and size, convert the whole into a finely granular mass.

The increase of arrangement is traced through the lavas with interspersed crystals, becoming decidedly porphyritic, until at length we find the whole a congeries of crystals.

In the older rocks of igneous origin a similar gradation is observable — through homogeneous pitchstone, pitchstone with globules, to pitchstone with crystals; — through claystone, claystone with concretions, with felspar crystals, with felspar, and quartz crystals; — through amorphous felspar, with felspar crystals, with felspar and quartz crystals, with felspar, quartz, and hornblende crystals, passing to sienite, — with felspar, quartz, and mica, scarcely distinct from granite.

The process of crystallisation being determined by the attractions of the particles, it by no means follows that the most infusible substance in an igneous fluid, or the most insoluble in an aqueous solution, should be the first to crystallise. In either case the particles of different kinds are mixed together; and it depends upon their relative elective attractions and cohesive forces, what crystals shall be the first generated. Now as the elective attractions between particles of different nature, superadded to the common force of cohesion, will tend to bring these together with more energy than the homogeneous particles, it follows that, in most instances, crystals compounded of several ingredients should be formed before those which consist of one simple substance; and this seems to explain the remarkable general fact, that quartz, the most infusible portion of granite, should be impressed by the previously formed crystals of felspar and mica.

Nevertheless, the degree of infusibility of the ingredients must be allowed to have a considerable influence in determining the order of crystallisation; because, in the first place, no crystal can be formed at a heat sufficient for its entire fusibility; and, 2dly, the action of heat seeming to be directly opposed both to elective attraction and the force of cohesion, if the fusing points of the materials be very unequal, the refractory substance may be collected together at a heat too great to permit any other part of the compound to solidify.

However, as in real solution and fusion we must in general suppose the materials resolved into their atomic constituents, the former state of things seems likely to be most common; and we ought in consequence to expect that a portion of the most abundant substance should remain till the last, and appear as a homogeneous enveloping base, whether crystallised or not.

This is remarkably the case with granite, which appears to have been once a melted fluid, consisting of the ingredients of felspar and mica, with an excess of silica; and this often remains not exactly as an enveloping paste, but in detached and irregular masses, filling the vacuities between the crystals of felspar and mica.

The *rate of cooling* is shown by Mr. Watt's experiments to have a most decided influence on the ultimate condition of earthy masses solidified from igneous fusion; the degree of pressure under which the solidification happens is also influential, by introducing *a new force*, to modify the relative molecular attractions. Of this sir James Hall's experiments on powdered limestone offer a satisfactory proof. Under a pressure which prevents the escape of its carbonic acid, limestone undergoes fusion, and assumes different degrees of consolidation and crystallisation, according *to the pressure.*

The principal products of volcanic action are known to us in the form of slender lava currents, and scattered scoria and ashes, which are all cooled and solidified *in* *the air* with greater rapidity, and under less pressure, than under the deep roots of a volcanic mountain. The same materials which, cooled at the surface of the earth, may be of glassy nature, as obsidian, or cellular, as most lava, may be, and probably are, at great depths in the earth's crust, or even under the sea, solidified with structures as highly crystalline, and in masses as dense, as those of granite or greenstone. And as in fact we know, from careful observation, that granites, greenstones, and other ancient rocks of igneous origin, *were* solidified under the pressure of the sea, and generally below a great mass of strata on its bed, it is not without good reason that modern geologists have drawn a line of distinction between the *plutonic* rocks, elaborated in the deep recesses of the earth, and the *volcanic* products, which are solidified at or near the surface. This distinction is indeed one of *degree*, and may be misapplied, and is neither complete nor exact when used, as it frequently is, absolutely to separate the consideration of the old and the modern products of heat. There are crystallised rocks among the products of modern volcanos, and glassy lavas among the ancient strata; basalt is both an ancient and a modern product; yet, as a general rule, it is true that the ancient igneous rocks possess those characters which we may believe to belong to slower cooling under greater pressure than the lavas which flow from subaerial volcanos have experienced. A philosophical consideration of the subject will always recognise the essential differences of subterranean, submarine, and subaërial solidification, as independent of geological antiquity; and philosophical observation will gradually enable us to detect these differences, and to employ them in tracing the changing conditions of the terraqueous globe.

Mineral Composition of Unstratified Rocks.

In those rocks of igneous origin, which permit the ingredients of which they are composed to be clearly distinguished, one mineral substance is almost universally found, viz. felspar, which equally abounds in the oldest granites and most recent lavas, and occurs, though not in equal abundance, in rocks of very different weight, colour, and chemical composition.

Very frequently, though not universally, we detect another mineral, which, under two forms, has been called by two distinct names, augite and hornblende (pyroxene and amphibole of Haüy). These, by the admirable researches of Rose and Mitscherlich, have been shown to acquire their characteristic differences of crystallisation from the *rate of cooling* to which they have been subjected. This protean mineral (which varies greatly in its chemical composition, by the substitution of different ingredients in combination with silica) constitutes a great proportion of the substance of greenstone and basalt, and many congeneric rocks. In general they present themselves under different circumstances from those which accompany rocks allied to granite, but offer near approximations to some of the products of actual volcanos, the flags of melting furnaces, and other fruits of artificial heat.

These two minerals, felspar and hornblende, appear at opposite points of the circle of plutonic and volcanic, of ancient and modern igneous products; so that mineralogists have generally found reason to coincide with the opinions of Cordier and Scrope, and to adopt them as the elements for a fundamental classification of the rocks of fusion.

Thus we have two series of rocks, viz. felspathic and augitic (or hornblendic) rocks, of every geological age, which, in the extremes (as granite and basalt, among the ancient, and trachyte and basalt, among the modern rocks), are perfectly and strikingly different; but yet graduate into one another by innumerable variations, which demonstrate the similarity of origin of all the unstratified rocks, and at the same time open wide fields of inquiry into the causes and effects of their differences.

Besides these predominant and typical minerals, others are frequently observed to modify very much the characters of igneous rocks, as mica, quartz, garnet, schorl zircon, olivine, mesotype, epidote, hypersthene, diallage oxydulous iron, iron pyrites; cyanite, pinite, spodumene, topaz, beryl, corundum, chromate of iron, prehnite, apatite, sphene, molybdena, &c. also occur—in particular rocks even abundantly.

According to the views previously established, every definite chemical mixture of earthy substances in fusion may be of crystalline, earthy, or vitreous texture; of uniform or unequal aspect in its parts; compact, cellular, or spumous; according to the circumstances of solidification.

The most correct way of describing a rock would be to give the formula of its mineral composition; but in uncrystalline masses this cannot be done, and the chemical composition of the same rock is not the same in even neighbouring parts. Geologists, therefore, whose more immediate object is to record the principal phenomena associated with rocks, have generally preferred to give distinctive names to those *aspects* of solidified igneous products which depend rather on the circumstances of their solidification, and indicate characteristic physical conditions of the globe, than on original and real differences of their own nature. Thus igneous rocks, with crystals lying detached in an uncrystallised basis, are generally called porphyries (as felspar porphyry, clay porphyry, trap porphyry, &c.); such as have concretions of quartz or mesotype, in place of those cavities which occur in modern lavas, are called amygdaloids. This method, though not strictly scientific, will perhaps always prevail; because the variations to which these rocks are subject are such as to baffle all mineralogical strictness; and because the most prominent and characteristic circumstances which accompany them, the form and manner of their exhibition, their relative antiquity, and the induration, metamorphism, and elevation of strata, appear but very indistinctly related to the formulæ which represent their chemical or mineralogical nature. On this ground Dr.

MacCulloch justifies his classification; in which rocks are often grouped under one head, not because they consist of the same ingredients, or of similar combinations of related minerals, but because they are related in age or position with regard to the strata, or fulfil other geological functions in common. In popular language, the mutual mixture of the crystals constitutes *granitic;* the separation of certain crystals defines the *porphyritic;* and peculiar divisional planes characterise the *basaltic* rocks; but every one of these circumstances belongs to almost every combination of felspar, quartz, mica, and hornblende. If we bear in mind that, in describing phenomena (for which chiefly technical names are useful), the first question to be answered is always with *what* these phenomena are associated, we shall see great reason to regret the neglect of eminent modern observers, who are satisfied with such terms as "trap" (which may be felspathic or hornblendic, porphyritic or amygdaloidal), or "granite," which may be a binary compound of felspar and quartz; a ternary mixture of quartz, felspar and mica; a quaternary union of quartz, felspar, mica, and hornblende, with or without large interspersed crystals of felspar, titaniferous iron, molybdena, apatite, &c., or may have the mica replaced by other congeneric substances.

This has been forcibly pointed out by Mr. Scrope, who has proposed a very intelligible plan of arrangement for volcanic rocks, on the basis of the relative abundance of the two conspicuous minerals felspar and hornblende (or augite), which, as before observed, compose the greater part of the igneous rocks of every age.

Mr. Scrope's synopsis of the species of volcanic rocks is as follows. (*Journal of Science,* vol. xxi.)

Trachyte.

A. Compound trachyte with mica, hornblende, or augite, sometimes both, and grains of titaniferous iron.

B. Simple trachyte, without any visible ingredient but felspar.

C. Quartziferous trachyte, containing numerous crystals of quartz.

D. Siliceous trachyte, when there appears to have been introduced a great quantity of silex into its composition.

Greystone.

A. Common, consisting of felspar, augite (or hornblende), and iron.

B. Leucitic greystone, when leucite supplants the felspar.

C. Melilitic greystone, when melilite is substituted for that mineral, &c.

Basalt.

A. Common basalt, composed of felspar, augite, and iron.

B. Leucitic, when leucite replaces the felspar.

C. Basalt, with olivine in lieu of felspar.

D. Basalt, with hauyne in lieu of felspar.

E. Ferruginous basalt, when iron is the predominant ingredient.

F. Augitic basalt, when augite or hornblende composes nearly the whole of the rock.

If our knowledge of the true composition of many of the old rocks of fusion were perfect, we might propose for them a scale of classification parallel to that which Mr. Scrope has given for volcanic rocks. Of such a scale the following would appear to be the elements:—

Division I.—*Felspathic.*

Rocks in which the characteristic and most abundant mineral, felspar, is not at all or but slightly mixed with hornblende, augite, or their congeners, hypersthene, diallage, &c.

Ancient.	*Modern.*
Granitic and most porphyritic rocks.	Trachytic rocks of Von Buch, Cordier, Scrope, &c.

Division II.—{ *Hornblende, Augite, &c.* } *Felspathic.*

Rocks in which felspar is mixed in nearly equal proportion with hornblende or augite, or their congeners, hypersthene, diallage, &c.

Ancient.	*Modern.*
Sienitic and greenstone rocks.	Greystones of Mr. Scrope.

DIVISION III. — *Hornblendic, Augitic, &c.*

Rocks in which hornblende, augite, hypersthene, or diallage predominates over the felspar (or its representative olivine, &c.), and sometimes constitutes the whole mass of the rock.

Ancient.	*Modern.*
Basaltic series of most authors.	Basaltic series of Scrope.

To each of these three divisions belong the granular, earthy, compact, resinous, and vitreous *textures;* porphyritic, concretionary, amygdaloidal, and cellular *structures;* cuboidal, prismatic, spheroidal, or irregular *divisional planes.* (Among recent igneous rocks the cellular and vitreous structure passes to spumous and filamentous: — pumice and scoria.)

To each of them belongs also a peculiar set of stratified analogues—as gneiss to granite; some hornblende slates to greenstones; wacké to basalt, — which are often embarrassing to the observer, and perplexing to the reasoner, even with the advantage of Mr. Lyell's views of "metamorphic" rocks, (for which consult a future section).

Exposed to the wasting agency of the atmosphere and water, few resist decomposition, and then yield clay or sand, often of great fertility.

A classification and nomenclature upon this system, which should embrace the igneous rocks of all ages, might, if accepted generally among observers, confer great benefits on geology. It would, however, necessitate an almost total change of descriptive names, and would render it indispensable for geologists to study mineralogy with more care than is now given to that rather difficult subject. It seems therefore unlikely that success would attend such a system if proposed at this time, more especially when we remember how very little regard has been paid in England to the classification and nomenclature of mixed rocks devised by M. Brongniart.

The system alluded to is, however, well worthy of consideration; and being much and usefully employed on the Continent, it appears proper to offer the following brief account of that portion which relates to our present subject.

Mixed Rocks.

I. Crystallised isomerous * rocks, in which the constituent parts are equally blended.

A. Felspathic rocks, the characteristic mineral being felspar.

1. Granite.—Composed of laminated felspar, quartz, and mica.
2. Protogine.—Composed of felspar, quartz, steatite, or talc, or chlorite, with little or no mica.
3. Pegmatite, or graphic granite.—Consisting of laminated felspar and quartz.
4. Mimose.—Laminated felspar and augite.

B. Hornblendic rocks, the characteristic mineral being hornblende.

1. Sienite.—Composed of laminated felspar, hornblende, and quartz, the first predominating. One of the most remarkable varieties is the zircon sienite of Norway.
2. Diabase, or greenstone.—Composed of disseminated hornblende and compact felspar. (The orbicular greenstone of Corsica is a singular variety.)

II. Crystallised anisomerous rocks, in which the constituent parts are not equally mixed.

A. Basis of serpentine with imbedded minerals.

Ophiolite.—In this occur oxydulous iron, chromate of iron, diallage, garnet, &c.

B. Basis of cornean, with imbedded minerals.

1. Variolite.—It contains nodules or veins, calcareous or siliceous, not older than the base.
2. Vakite.—The base is wacké, with augite, mica, &c. imbedded.

* From ισος, equal, and μερος, a portion.

C Basis of hornblende or basalt, with imbedded minerals.

1. Amphibolite.—Basis of hornblende.
2. Basanite.—Basis of compact basalt, with disseminated minerals. (Basalt is viewed as a mixture of augite, olivine, and titaniferous iron.)
3. Trappite.—The basis hard and compact, holds mica, felspar, &c.
4. Melaphyre, or trap porphyry.—The basis is a black petrosiliceous hornblende (by other writers said to be augite), with crystals of felspar.

D. Basis of petrosilex coloured by hornblende.

1. Porphyry.—Basis a paste red or reddish, with crystals of felspar.
2. Ophite.—Basis a paste green, with crystals of felspar.
3. Amygdaloid.—Holds nodules similar (except in colour) to the basis.
4. Euphotide, or diallage rock.—Encloses crystals of diallage.

E. Basis of petrosilex, or compact felspar.

1. Eurite.—The disseminated minerals are mica, felspar, garnets, &c.
2. Leptenite.—Basis of granular felspar with mica and quartz.
3. Trachyte.—Encloses crystals of glassy felspar in a dull (earthy) basis.

F. Basis of claystone (an earthy or granular felspar).

1. Clay porphyry.—The enclosed crystals are felspar.
2. Domite porphyry.—The enclosed crystals are mica.

G. Basis of pitchstone or obsidian.

Stigmite.—Encloses crystals of felspar (pitchstone porphyry of authors).

H. Base undetermined.

Many kinds of lava.

Gradations among Igneous Rocks.

The rocks of igneous origin exhibit among one another particular relations and gradations, which it is important to attend to before proceeding to discuss some other points of their history. That such variations should take place among the felspathic rocks on the one hand, and among the augitic rocks on the other, was quite to be expected; but, in fact, between these generally opposite groups some transitions are known. Dr. Hibbert Ware has noticed, in his work on the Shetland islands, a gradation from binary granite (composed of quartz and felspar) to a basaltic rock (composed of hornblende and some felspar). He also describes a transition from felspar porphyry into granite, near Hillswick Ness.

M. Necker informs us, that, in the depth of the valley of the Valteline, which is in the anticlinal axis of the Alps north of Como, three great protuberances of granite arise, surmounted by gneiss and mica schist. The granite resembles that of the Valorsine and Mittenwald, in the Tyrol, being composed of grey quartz, white felspar, and black mica, and it throws up veins into the schistore rocks. This granite is seen to pass, by an easy gradation, first to common sienite, then to sienitic hypersthene, some of which has white felspar and black hypersthene, some green hypersthene, and greenish felspar. This rock varies also in the size of the grain and the reflections of the hypersthene; it partly resembles diallage rock and partly greenstone; the different varieties are intermingled, and the complication is augmented by contemporaneous veins of fine-grained granite entering the hypersthene. The granite is traversed by veins of quartz enclosing black tourmaline. (*Bibliothèque Universelle,* 1829.)

This description of M. Necker will remind the geologist who has examined the granitic region of the Caldew, in Cumberland, of what is there a probable, but not a certain, inference, the connection of the granite of the base of Saddleback (which, like that of the Valteline, is composed of grey quartz, white felspar, and black mica) with the hypersthenic sienite of Carrock Fell, which passes into common sienite, and in places cannot be distinguished from diallage rock or greenstone. It often encloses magnetic iron ore.

Von Buch speaks of the transition of "gabbro," or diallage rock, to granite, in the island of Kielvig.

No author has given more attention to the transitions which obtain between the various pyrogenous rocks, nor with greater success, than the late Dr. MacCulloch, to whom, indeed, modern geologists owe a large debt, for the clear and masterly conceptions he has published on this subject. He tells us, concerning the granites of Aberdeenshire, which are generally composed of quartz, felspar, and mica, that in this compound hornblende is occasionally substituted for mica; that the quartz sometimes fails; that this hornblendic mass becomes fine-grained, and passes to greenstone, basalt, and an earthy trap-like claystone.

Von Dechen, in the German translation of De la Beche's manual, expresses very clearly the state of opinion among geological observers, as to the gradation in character from one to another, of all the igneous rocks. Thus *granite*, by replacement of its mica with hornblende, changes to *sienite;* by containing detached felspar crystals, it becomes *porphyritic;* and when reduced to very fine grains, we can entirely corroborate Von Dechen in saying that it is undistinguishable from *felspar porphyry*. A more earthy basis gives us *clay porphyry;* a concentric internal arrangement makes *globular porphyry* (kugel porphyr).

Trachyte and *porphyritic trachyte* are a parallel series to granite and porphyritic granite; in an earthy state they constitute *domite.*

Sienite and felspar porphyry pass by variation of mineral ingredients to the vague group of *greenstones* or *traps,* in which hornblende or augite forms a prominent part of the mass. Of these, *diorite* (diabase or greenstone) is related to sienite (the gradations being called greenstone sienite, and sienitic greenstone, &c.). The total absence of felspar turns such greenstones into *hornblende rocks;* diorites with extremely fine grains are called *aphanite,* and these cannot often be separated from the more quartzose rocks, usually called *hornstone* (by other writers, petrosilex or cornean). Such a basis, with crystals of felspar and hornblende, is often called greenstone porphyry, green porphyry, &c.

Dolerite (mimose of Brongniart) differs from diorite by holding augite instead of hornblende; its fine-grained varieties pass into the vague group of *basalts* or whinstones, which, if restricted to a common definition, should contain magnetic (titaniferous) iron ore.

Augite alone rarely constitutes a rock (lherzolite, or *augite rock*). The compact rocks, like aphanite, compact basalts, &c., change to *amygdaloids*, when they include masses of extraneous minerals, which fill, or appear to fill, cavities in the stone like those common in lava; the basis of many amygdaloids is earthy, and is called *wacké*. The rock called *gabbro* (euphotide, diallage rock, hypersthene rock) is characterised by its mixed felspar and diallage, or hypersthene; and *serpentine* is a corresponding but uncrystallised mass of felspar and schiller spar, usually enclosing several talcose minerals.

Felspar, the most abundant of all the minerals in rocks of igneous origin, is variable as to the alkaline portion of it; for in some (common felspar), potash — in others (labradorite), soda — in others (albite), lime and soda, are found. Von Dechen tells us that common felspar is mostly found in quartziferous and hornblendic mixtures; labradorite in mixtures with augitic minerals; while albite, though sometimes mixed with common felspar, constitutes but a small part of the masses of igneous rocks.

Chemical Composition of the Rocks of Igneous Origin.

The permutations which take place among the mineral ingredients of igneous rocks are easily and clearly intelligible by considering the chemical composition of these minerals, which, as in the case of hornblende, augite, hypersthene, and diallage, often differ from one another, rather by the crystalline arrangement of the parts, or the substitution of mutually replacing substances, than by any essential and constant characters. If the pyrogenous rocks of every age be restored in imagination to their ancient state of fluidity, and their chemical constitution in this state be calculated from the analysis of their integrant minerals, we shall find a remarkable general analogy running through them, and be able to perceive, in some instances, the reason of those *gradations* in mineral characters, which link into one system a long series of seemingly different rocks.

Mr. De la Beche has given some calculations on this subject, founded on the assumed elementary composition of minerals which are of frequent occurrence in igneous rocks. Some of the analyses adopted by Mr. De la Beche, and the calculations founded on them, are appended, with a few additions of our own.

Analysis of Minerals in Igneous Products.

	Silica.	Alumine.	Lime.	Magnesia.	Potash.	Soda.	Oxides of Iron and Manganese.	Fluoric Acid or Boracic acid.	Water.
Felspar, common	64·0	18·9	0·8	-	13·7	-	0·7		
Felspar, albite -	69·5	19·4	0·2	0·1	-	10·0	0·3		
Mica - -	46·1	26·2	0·4	5·0	10·1	-	8·8	1·1	2·0
Hornblende -	45·7	12·2	13 8	18·8	-	-	7·5*	6·5	-
Augite of Etna †	52·0	3·3	13·2	10·0	-	-	16·7	-	4·8
Tourmaline -	36·0	35·8	0·3	4·4	0·7	2·0	15·3	3·5‡	-
Hypersthene -	54·2	2·3	1·5	14·0	-	-	24·5	-	1·0
Diallage -	47·2	3·7	13·1	24·4	-	-	7·4*	-	3·2

In this list, the most variable substances are mica, augite, and hornblende; the most uniform is felspar. The variety of composition in mica is extraordinary, as the following comparative table, in which the four

* Protoxide of iron. † Black augite analysed by Vauquelin.
‡ Boracic acid.

varieties are classed according to the predominance of magnesia, alumina, potash, or oxide of iron, will show.

	Silica.	Alum	Magnesia.	Potash.	Oxide of Iron and Manganese.	Fluoric Acid.	Analysts
Mica, magnesian of Siberia	42·5	16·0	26·0	7·6	5·0	0·7	Rose.
aluminous of Sweden	46·4	34·8	-	8·8	5·8	0·8	Rose(3 analys.)
ferruginous of Siberia	42·5	11·5	9·0	10·0	22·0	-	Klaproth.
Potash of Moscow	40·0	11·0	19·0	20·0	8·0	-	Vauquelin.
	171·4	73·3	54·0	46·4	40·8		
Average	42·8	18·3	13·5	11·3	10·2	0·4	= 96·5.
The sum = 100 gives	44·3	18·9	14·9	11·7	10·6	0·4	= 99·9.

Granite, of the ordinary kind, compounded of quartz, felspar, and mica, varies greatly in the proportion of these substances, yet the fused glasses from which these various products have crystallised, might differ only by small variations in the proportions of the ingredients.

Granite, composed of quartz 2 parts, felspar 2 parts, and mica 1 part, would, according to Mr. de la Beche's calculation, be represented in column 1. of the table below; and porphyritic granite, composed of quartz 2 parts, felspar 3 parts, and mica 1 part, in column 2.; and we have added binary granite (felspar 3 parts, and quartz 2 parts) in column 3.

	1.	2.	3.
Silica - - -	74·84	73·04	75·1
Alumina - -	12·80	13·83	10·9
Potash - -	7·48	8·51	9·8
Magnesia - -	0·99	0·83	
Lime - -	0·37	0·44	0·5
Oxide of iron -	1·93	1·73	0·4
Oxide of manganese	0·12	0·10	
Fluoric acid -	0·21	0·18	

The differences of the ultimate analysis are very much smaller than the different aspect of the rocks might lead us to expect.

Sienite, composed of quartz, felspar, and hornblende, in equal proportions, would be represented in the subjoined table by column 1.; sienitic granite in which quartz, felspar, and mica shonld appear in equal proportions, in column 2.; schorl rock, composed of equal parts of quartz and schorl, in column 3.

	1.	2.	3.
Silica - - -	69·91	63·96	68·01
Alumina - -	10·37	14·32	17·91
Potash - -	4·55	5·94	0·35 0·98 } soda.
Lime - -	4·86	3·73	0·14
Magnesia - -	6·26	5·94	2·22
Oxide of iron -	2·69	4·06	6·85
Oxide of manganese	0·07	0·21	0·81
Fluoric acid -	0·50	0·65	1·79

Turning from these rocks, in which quartz is an essential constituent, to those which are composed of felspar united with hornblende or some analogous mineral, we have greenstone (felspar and hornblende in equal parts) represented in the first column of the next table;

	1.	2.	3.
Silica - - -	54·86	59·14	58·42
Alumina - -	15·56	10·59	13·86
Potash - - -	6·83	6·83	9·10
Lime - - -	7·29	1·13	4·87
Magnesia - -	9·39	7·00	8·13
Oxide of iron -	4·03	12·62	2·00
Oxide of manganese	0·11		
Fluoric acid -	0·75		
Water - - -	-	0·50	1·06

hypersthene rock (common felspar and hypersthene in equal parts) in column 2.; and diallage rock (two thirds of common felspar and one third of diallage) in column 3.

Serpentine, usually considered to be little else than diallage or schiller spar, seems to be well represented in general, by supposing it a hydrated subsilicate of magnesia; and contains besides chrome and other metals, alumina, &c. (in all 5 per cent.): —

Silica	about	42
Magnesia	—	38
Water	—	15

A subsilicate of magnesia would contain very nearly the same proportions of the earths.

Among the rocks known to be of volcanic origin, porphyry, which graduates to claystone, and trachyte, — trachyte, which in a vitreous state becomes one kind of obsidian,—and pumice, which is a spumous or filamentous form of obsidian, —appear to compose one long series of felspathic compounds, remarkably analogous to granite, both by mineral variations (where these can be clearly seen) and by chemical composition. The analysis of obsidian from Hecla, by Vauquelin, yielded the results in column 1.; while in column 2. is the composition of a siliceous granite, which we have calculated from the proportions of quartz 3 parts, common felspar, albite, and mica, each 1 part. In column 3. is the analysis of

	1.	2.	3.	4.
Silica - -	78	80·1	80·2	80·9
Alumina -	10	10·0	12·7	10·2
Potash - -	6	4·0	-	1·7
Lime - -	1	0·7	1·1	0·2
Magnesia - -	-	-	-	0·8
Soda - -	1·6	1·7	1·9	3·3
Oxide of iron and manganese	1·0	1·5	1·1	1·5
Fluoric acid & water	-	0·5	-	0·5

Newry pitchstone by Knox (W. Phillips's Mineralogy, the bitumen and water omitted); and in column 4. a granite of 3 parts quartz, 2 parts albite, and 1 part mica.

Pumice, the last term of this siliceous series, is stated by W. Phillips to be composed of

Silica, 77·5.	Potash and soda, 3·0.
Alumina, 17·5.	Oxide of iron, 1·7.

As an example of greystone? lava, Dr. Kennedy's analysis of the compact lava of Calabria may be quoted: —

Silica, 51.	Soda, 4.
Alumina, 19.	Iron, 14.
Lime, 10.	Water, 1.

Basalt, which belongs to almost every geological age, constitutes the last term of this series, in which silica is diminishing continually. It is very irregular in composition, as might be expected from the character of its predominant ingredient, hornblende or augite. The basalt of Hasenberg in Saxony, according to Klaproth, is composed of

Silica, 44·50.	Soda, 2·60.
Alumina, 16·75.	Oxide of iron, 20·00.
Lime, 9·50.	Oxide of manganese, 0·12.
Magnesia, 2·25.	Water, 2·00.

That of Staffa, according to Dr. Kennedy,

Silica, 48.	Soda, 4.
Alumina, 16.	Muriatic acid, 1.
Oxide of iron, 16.	Water, &c., 5.
Lime, 9.	

Exterior Forms of the Masses of Igneous Rocks.

Interposed Beds. — As before observed, the want of stratification is one of the characters of igneous rocks; yet there are two cases in which they show themselves in stratiform masses, which seem exceptions to the rule.

One of these cases has been amply treated by Macculloch, in his account of the Island of Skye; examples of it may also be seen in the Island of Arran. The reader will understand the circumstance alluded to by consulting *fig.* 81., where (*d*) represents a vertical mass

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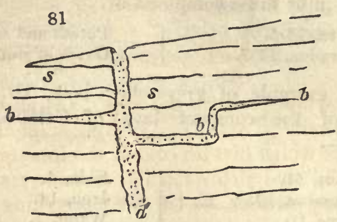

of igneous rock (greenstone in Skye, pitchstone in Arran) filling a fissure in the stratified rocks, (*s*) and (*b*) an interposed bed of the same igneous rock forced in a liquid state between two strata originally contiguous.

The second case is exemplified in the basaltic formation of Antrim, where several successive layers of melted rock, the fruit of many successive volcanic eruptions, are heaped one upon another as they were originally poured out upon the chalky bed of the ancient sea. — Another example is furnished by the volcanic rock called "toadstone *," which in Derbyshire lies in one or more stratiformed masses between the beds of mountain limestone, as probably it was originally effused on the surface of the lower bed. The upper surface of the toadstone is said to be remarkably undulated. A third example is found in the region round Crossfell, where a basaltic formation, called the "whin sill," is widely spread in the midst of the limestones and sandstones, over some of which it appears to have poured as a submarine current of lava, while through and amongst others it was per-

* Is this word originally *todtstein*, derived from German miners? It would in this case signify rock, which in a mining country is dead, or unproductive of mineral treasures, a character generally applicable to this rock.

haps forcibly injected. The diagram No. 82. shows the manner in which the basaltic mass (*b*) grows thinner

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in one direction (towards the west), and also the occurrence of a mineral vein (*v*) (yielding sulphuret of lead) in a fissure which divides equally the limestone and the "whin sill," and yields valuable metallic ores in each.

Overlying Masses. — In the preceding instances, igneous rocks are included *between* sedimentary strata; overlying masses, as they are called, spread irregularly *over* a surface of other rocks without being themselves covered by any. The same overflow of melted rock may, in one part, appear an overlying mass, and, in another, an interposed bed, as in the Clee Hills, in Salisbury Craig, near Edinburgh, &c. The porphyritic summit of Ben Nevis is an overlying mass, which has burst up through the granitic base of the mountain ; the porphyritic mass at the lower end of St. John's Vale, Cumberland, is similarly circumstanced in relation to the slate rocks of that region; and the phenomenon is common. It is perfectly paralleled by what happens in many eruptions of lava, and was well illustrated by the great Icelandic lava currents in 1783.

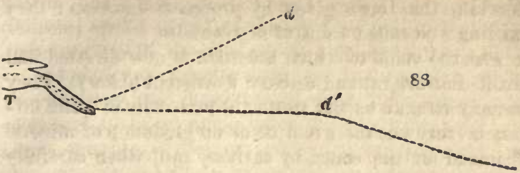
Fissures. — In all these cases the situation of the once melted rocks is easily explicable by supposing, what in some cases is known to be the fact, that the horizontally extended masses of igneous rocks have been forced upwards through tubular passages or fissures, as happens at this day at the summit or on the sides of active volcanos. Such fissures or tubular passages occasionally appear connected in one long or in several short parallel lines; as, for example, among the silurian strata the line of eruptions marked by the trap rocks of the

Wrekin, the Lawley, Caer-Caradoc, &c.; and, among existing volcanos on a greater scale, the *linear volcanos*, to which Von Buch was the first to direct attention. Great fissures, such as here alluded to, may be extremely irregular; the strata through which they break may be thrown into great confusion; their parts may be disjoined and separated by cavities. Into these irregular hollows the fused matter sometimes has been forced; and not unfrequently large and small portions of the broken strata are inclosed in the midst of the igneous rock; while sometimes portions of the latter have flowed into cavities in the stratified masses, from which it is difficult to trace their connection with the main stream.

Such phenomena may be well studied in Salisbury Craigs, and other localities near Edinburgh; in Teesdale; the Caradoc Hill, &c.

Dykes. — A still more common form of appearance among igneous rocks is what is called a dyke, which agrees with the general description of similar rocks occupying a fissure; nor in some cases is there any distinction. But dykes, when seen in perfection, as in the Island of Arran, the coal-field of Durham and Newcastle, the limestone of Teesdale, the lias near Stokesley, the silurian rocks of Shropshire, or the slates of Snowdonia, present characters of greater symmetry, and claim a somewhat different origin. The fissures which inclose these trap dykes present often no trace of violent movement of the strata, which, on the contrary, sometimes appear level and undisturbed on both sides; these sides are remarkably parallel, plane, and either vertical, or slightly inclined, so that the inclosed mass of rock looks like a continuous wall. On the surface the dyke lies usually in a straight line from a few hundred yards to ten, twenty, and more miles in length.

Archdeacon Verschoyle has described several trap dykes which range on the coast of Mayo and Sligo: one of them extends altogether, in an east and west direction, sixty or seventy miles. One of the dykes, which is represented in the diagram No. 83., continues in a



T. The great mass of basalt in Teesdale.
d. A straight dyke passing East 20° North.
d'. Another, passing generally to the South of East.

perfectly straight line, across the Durham coal-fields, twenty miles, in a direction E.N.E.; the other, starting from the same point (near Middleton in Teesdale), extends into the eastern part of Yorkshire, nearly reaching Robin Hood's Bay, a distance of seventy miles, in an E.S.E. direction.

In some districts, rock dykes are wonderfully numerous. Forty-four trap dykes of various kinds were carefully noticed and measured by the author of these remarks, in a few miles of the coast of the Island of Arran, between Brodick and Lamlash. They abound no less on the western side of the same island at Tormore.

Veins.—One of the most interesting forms of occurrence of igneous rocks is that of veins, which penetrate and ramify irregularly in the fissures of the neighbouring rocks. These veins sometimes appear insulated in the midst of rocks more or less different from them in composition, except at the common surfaces, where the substance of the vein and the inclosing rock are intimately united by intermediate characters of mineral composition or undistinguishable blending of the parts. In this manner granite frequently incloses parts in which hornblende, or mica, are particularly abundant or remarkably deficient; the redundancy and defect being equally referrible to circumstances which operated during the crystallisation of the stone. To such spherical, nodular, or elongated parts of a rock, the title of contemporaneous veins has been given by professor Jameson: they may also be called veins of segregation.

But the veins to which attention is now directed had a different origin, and disclose a different history. They sometimes may appear insulated in a mass of quite different rock, but there is little or no gradation of mineral character at the common surface, and, when carefully traced, the veins are found connected with larger masses of their own substance at no great distance. (See diagram No. 84. p. 76.) Recollecting that all the igneous rocks, found intermixed with the strata, have been pressed by considerable mechanical force, it is an unexpected fact that veins, such as are now described, branching off into the minute cracks and fissures of the stratified masses, should be witnessed almost exclusively in granitic and sienitic compounds. Nor is our surprise lessened, when we find the lava or existing volcanoes occasionally assuming the shape of veins, as well as of dykes, in the fissured substance of the crater and sides of the mountain.

Why, for example, should it almost never occur that the substance of porphyritic and basaltic dykes, whether they pass through slate, coal, sandstone, or limestone, is extended from the main body into the numerous small cracks and fissures which margin the dyke; while, on the other hand, there are few situations where granite comes in contact with gneiss, clay slate, limestone, mica slate, or hornblende slate, without throwing off many branches into those rocks?

One reason may be, that the porphyritic and other 'trappean' dykes, injected among the strata while they were cold, lost, like lava at the surface, their heat and fluidity too rapidly to penetrate the small fissures; while the enormous masses of granite in contact with the strata which they penetrate, may have retained their fluidity through a considerable period. But this is probably not the whole truth. One effect of the igneous rocks is to produce fissures in the stratified masses; and it is very conceivable that the small lateral fissures alluded to did not exist till after the partial or complete solidification of the rock which filled the dyke.

Examples of granite veins are innumerable, though a few years only have passed since they were deemed too rare to be of much value in supporting the Huttonian doctrine of the crystallisation of this rock from igneous fusion. Their importance was most fully understood by Dr. Hutton, and his able supporter Playfair, whose notices have not lost their value in the eyes of modern inquirers. Distinguishing between the veins which are clearly and completely traced to the large masses of granite rock, and such as appear insulated, Playfair describes the latter class as occurring in the Western Islands, particularly in Coll, where they traverse the beds of gneiss and hornblende schist. They are several fathoms in thickness, obliquely intersecting the nearly vertical planes of the strata. The beautiful Portsoy granite is a vein or dyke; a similar granite is found inland, near Huntly. The bed of the river Tilt, in the distance of little more than a mile, is intersected by no less than six very powerful veins of granite, all of them accompanied with such marks of disorder and confusion in the strata, as indicate very strongly the violence with which the granite was here introduced into its place. (Dr. Macculloch's view of these phenomena in Glen Tilt is different.) "The second kind of granite vein is one which proceeds visibly from a mass of that rock, and penetrates into the contiguous strata. The importance of this class of veins, for ascertaining the relation between granite and other mineral bodies, has been pointed out (§ 82.); and by means of them it has been shown that the granite, though inferior in position, is of more recent formation than the schistus incumbent on it; and that the latter, instead of having been quietly deposited on the former, has been, long after its deposition and consolidation, heaved up from its horizontal position by the liquid body of the granite forcibly impelled against it from below." *

* Illustrations of the Huttonian Theory, Works, p. 312.

Among the cases quoted by Playfair in his further discussion of this subject, is the series of veins which accompany the junction of the granite and schist of Galloway. Sir J. Hall and Mr. Douglas, following the previous indications of Dr. Hutton and Mr. Clerk, traced the line of separation between the granite and schist all round a tract of country about eleven miles by seven, extending from the banks of Loch Ken westward; and in all this tract they found that wherever the junction of the granite with the schistus was visible, veins of the former, from fifty yards to the tenth of an inch in width, were to be seen running into the latter, and pervading it in all directions, so as to put it beyond all doubt that the granite of these veins, and consequently of the great body itself, which was observed to form with the veins one uninterrupted mass, must have flowed in a soft or liquid state into its present position.

Perhaps no better example of granite veins is known than in the mountain of Tornidneon, above Loch Ranza, which was examined by sir J. Hall. From a careful personal survey of this case, in 1826, the following notes and diagram (No. 84.) are extracted. The junction of granite and a dark quartziferous clay slate, with rather wavy laminæ, takes place nearly in a vertical line, rudely parallel to the lamination of the slate. The granite at a distance from the slate is very coarse grained (composed of quartz, felspar, and mica, occasionally with cavities inclosing those minerals distinctly crystallised), and sometimes porphyritic; but where it touches the slate it appears fine grained and much more compact. Veins pass from the granitic mass in various directions: a great vein, which incloses fragments of slate, divides itself, and crosses at different angles the slaty laminæ, but is not ramified into many small strings. In the large vein the granite is coarse, but in the small veins it is fine grained.

The substance of granite veins is sometimes undistinguishable from that of the great mass whence they spring, as in some of the veins which surround the granitic

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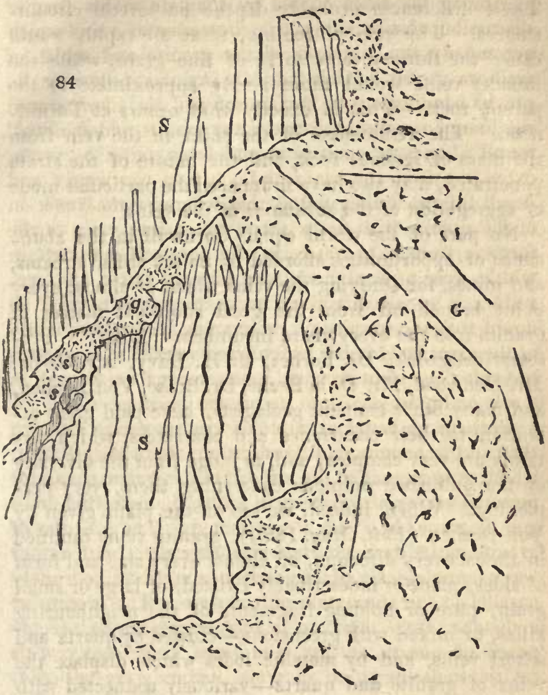


s. The slaty rock.
G. The mass of granite.
g. One of the veins. The style of dotting is intended to express th fineness or coarseness of grain in the granitic mass and veins.
s. Portions of slate included in the granite vein.

region of Galloway, and some of the veins in Glen Tilt; in other cases it is very much more fine in grain, and otherwise dissimilar to the parent rock, as at St. Michael's Mount, and in the case already mentioned at Tornidneon; and sometimes it is said by Playfair to be more crystallised in the veins than in the mass. These differences probably depend on several circumstances. The rate of cooling, if at all rapid, would cause the thinner veins to be of fine grain, while the broader veins would more nearly approximate to the parent rock. This is exactly what occurs at Tornidneon. The remoteness of the point in the vein from the mass of igneous rock, and the nature of the strata penetrated, may also have influenced the particular mode of aggregation of the substance of the veins.

No part of the world equals Cornwall in the abundance of opportunities afforded by its sea cliffs, streams, and mines, for studying the veins which at almost every point branch off from the great subjacent masses of granite into the everywhere incumbent "killas." Professor Sedgwick, Dr. Forbes, sir H. Davy, Mr. Carne, Mr. Henwood, Mr. De la Beche, Dr. Boase, Von Dechen, and many other eminent geologists, have paid great attention to their occurrence and characters, which certainly are very complex, and, to judge from the diversity of the published opinions concerning them, very perplexing. When, indeed, we see on the plans given by Von Dechen (*Phil. Mag.* 1829), granite veins ramified in almost every direction, of almost every size and form of sides, plane or indescribably twisted, of large or small grain, pure or holding fragments of the neighbouring killas, or mixed with greenstone—crossed by quartz and schorl veins, and by metallic lodes which displace the veins of granite and quartz—variously connected with serpentine masses and veins of steatite,—it is surely not surprising that phenomena so various and remarkable, exhibited incompletely, should, if studied without reference to other and less complicated examples, be the source of confusion and discord between perfectly impartial observers and reasoners. Nor is this all the difficulty: the general relation of the laminar structure of killas to the faces of the granite masses is extremely difficult to reduce to a clear statement. The killas is of most indefinite composition; the granite includes contemporaneous veins; and this same country is broken into innumerable parts by metallic lodes, elvan courses, and other accompaniments of subterranean dislocations.

Most thankful, therefore, should geologists be, that further investigation of the facts, on which so many hands have been employed, has been performed by Mr. De la Beche, whose report, accompanying the geological survey of Devon and Cornwall, has now passed through the press.

From professor Sedgwick's description of the magnificent phenomena of granite veins at Trewavas Head, about two miles west of Porth Leven (*Cambridge Philosophical Trans.*), we extract the following notice: —

"On reaching the beach, we first found the killas rocks intersected by many contemporaneous veins of quartz. Not many feet farther west we were surprised to observe an appearance of alternation between the slate on which we were advancing, and several thin beds of granite. One more especially, which towards its southern extremity was lost under the waters, preserved its thickness and conformity to the laminæ of the schist for more than 100 feet. But its true nature was easily determined in the other direction; for it gave out several smaller veins, then cut obliquely through the laminæ of slate, and at length contracted its dimensions, started entirely from its previous direction, and ran in a flickering line across the perpendicular cliffs. This vein is in no part more than two feet wide; yet it may be traced from the edge of the water to its termination in the cliff, nearly 400 feet.

"In the cliffs further west there are several granitic veins, which would be considered of no great interest if they had not been intersected by two other veins of different character, which must be classed either with the metalliferous lodes or the cross course of the country. One of them ranges nearly in the magnetic meridian, is about one foot and a half wide, and underlies east, two feet in a fathom. The other underlies in an opposite direction. They both contain quartz, oxide of iron, and apparently some fragments of clay slate. At the time of their formation, the mineral masses which they traverse must have undergone a considerable disturbance; for the broken ends of the schistose beds and granite veins, where they pass, are distinctly heaved from their original position.

"Still further west we found the rocks beautifully intersected by granitic veins; the higher part being traversed by innumerable ramifications, while the lower part is cut through by one well-defined vein about a foot thick, which, after keeping nearly in the direction of the beds of slate for about sixty feet, suddenly starts off at right angles to its former direction, and rises up to the top of the cliff. The whole system of veins here described afterwards unites in one trunk, which traverses a projecting ledge of rock, and descends obliquely into a mass of granite which forms the eastern side of the entrance into a singular natural cavern. Both sides of its entrance are of granite, but the roof is formed by undisturbed beds of killas. The granitic masses, however, soon contract their dimensions, and wedge out in the schistose rocks, which form both the roof and walls of the cavern, about 50 feet from its commencement.

"From the very point which is marked by so much confusion, two large veins, separated by a lancet-shaped mass of slate, rise towards the west at an angle of about 15°. Within a few feet of the other two, a third vein starts out nearly at the same angle, and proceeds in the same direction. These three veins are throughout nearly of the same thickness, viz. each about five feet. The highest, at some distance from its base, begins to ascend more rapidly, and is lost in the alluvial soil at the summit. The other two preserve their course, without being much deflected, for some hundred feet from the place where we first remarked them, and disappear behind a projecting part of the cliff. On turning this projecting ledge, we suddenly reached a recess, the lower part of which was filled with the ruins from the higher part of the overhanging rocks.

The western side of this recess is composed of killas intersected by some small granitic veins. A protruding mass of granite forms the base of the eastern side to the height of twenty-five or thirty feet. It is of a very singular outline, yet does not appear to have thrown the slaty laminæ reposing on it out of their usual direction.

"The mound of rubbish in the recess enables us to ascend more than half way up the cliff, and trace the two large veins before mentioned into an enormous bunch of granite, which here reposes on the top of the cliff, and is supported by undisturbed beds of slate; the line of demarcation being nearly horizontal, and at an elevation of sixty or seventy feet above the level of the beach. The denuded face of this bunch of granite is thirty or forty feet thick, and, in a section made farther from the cliffs, would probably be much more considerable; for the ground rises rapidly to the north, and it is impossible even to form a conjecture how far the cap of granite may extend in that direction.

"Two or three veins appear to take their origin from this anomalous overlying mass. One spreads out in minute ramifications towards the part of the cliffs which abuts against Trewavas Point, at the termination of the killas in that direction. Two others descend obliquely, and are lost behind the large mound of rubbish before mentioned."

Granitic *veins*, which ramify and pass irregularly for short distances from the great mass, are frequent; but *dykes*, which are of simple form, and cross with a certain regularity great breadths of strata, where no parent mass of the same nature is known, are very rarely granitic. If this seem a paradox, its solution may lead to important results. Could we behold enormous masses of porphyry, or basalt, below vast breadths of stratified sediments, as granite is commonly seen, there would probably be found porphyritic or basaltic veins passing from them into the cracks of the strata. If this is never the case, does it not show the peculiar mineral character of granite, and its peculiar effects on the adjoining rocks, to be the fruit of the local circumstances of its deep 'plutonic' origin? It is a 'hypogene' rock very slowly cooled; in other circumstances it would not appear as granite. In thin veins and parts remote from the great body it becomes a fine-grained or even compact mass, hardly different from the base of porphyry. What then prevents us from believing that many felspathic dykes, like the elvans of Cornwall and Cumberland, which are so very generally found on the borders of granitic districts, are really of granitic origin? This is a view which has become familiar to our minds, while traversing the vale of St. John's, Wastdale, and Shapfells, and which has already been advanced by MM. Oeynhausen and Von Dechen, while speaking of the geology of Cornwall. (*Geol. Proceedings*, vol. i.)

Amorphous Masses under all the Strata. — If granitic veins surprise us by their smallness and the perfection with which they have been injected into all the ramifications of a stratified rock, the vastness of the masses from which they arise is even more remarkable. For it is certainly true, that in every place, yet completely explored, the veins end downwards in granite formations, so extensive and unbounded, and appearing at so many points beneath the lowest strata, as to deserve, more than any other assemblages of mineral masses yet made known, the title of an universal formation. The differences which obtain between different sorts of granite are more striking to the eye than important in reasoning; for it has already appeared, that even when one of the constituent minerals, mica, is wholly absent, the chemical contents of this remarkable stone vary almost imperceptibly. (See p. 92.)

Internal Divisions of Igneous Rocks.

On this head it has not been found necessary to add to the remarks which will be found in Vol. I. p. 62.

Phenomena observed where Igneous Rocks come in contact with Stratified Masses.

Induration of Stratified Rocks.

One of the most usual effects of moderate heat upon argillaceous and arenaceous compounds is to indurate and condense their substance: considerable heat causes the grains to agglutinate into a "grit;" extreme heat fuses most argillaceous and many arenaceous rocks into a slaggy or glassy matter, which upon cooling remains vitreous, earthy, or crystalline, just as Mr. Watt found to happen to the basalt of Rowley Hills. In the slags of furnaces, several minerals have been found crystallised. The effects of the heated rocks which fill veins and dykes, and spread above and below argillaceous strata, are very similar. When dykes are of small breadth, the alteration which is seen in the neighbouring rocks is very slight. Of forty-four dykes composed of greenstone, claystone, and other igneous rocks, which were carefully observed and described by the author, as they occur on the shore of the Island of Arran, between Brodick and Lamlash, very few were found to have produced in the adjacent red sandstone more than a slight induration, in a very narrow space close to the dyke. Where two dykes crossed, it happened sometimes that a vitreous substance ran along the line of intersection.* But on the sides of large dykes, 20 to 60 feet wide (as, for example, the great dyke of Cockfield fell in Durham), the shales are highly indurated and otherwise altered, and the sandstones rendered as hard and solid as some sorts of quartz rock.† In Salisbury Craigs,

* These descriptions are unpublished.

† Mr. Murchison has found numerous examples of this effect in his survey of the trap rocks of the silurian system, as in Caer Caradoc, the Corndon Hills, the Stiperstone ridge, and many others. One of the Corndon dykes, forty feet wide, with prisms lying across the dyke, composed of greenstone varying to felspar, has indurated the neighbouring argillaceous beds for two or three inches, so as to make them like the substance known as porcelain jasper; and for twelve feet the induration is remarkable.

the greenstone which is intermixed with the soft sandstones and shales of the coal formation has hardened these beds at the surfaces of contact so as to convert them into a kind of jasper, which takes a good polish. Under Stirling Castle, in Teesdale, on the flanks of the Caradoc, by the Plas Newydd dykes on the Menai, and indeed generally where the rocks of igneous origin appear in great masses, this effect of consolidating the stratified rocks is conspicuous, and leads to important reflections concerning the changes which, on a greater scale, the whole series of stratified rocks may have undergone.

The induration of the strata is an effect quite distinct from their deposition, and appears to require the supposition of long continued application of heat. In surveying the different systems of strata in succession, we readily perceive that, independent of the local influence of particular masses of igneous rocks, whose influence extends only a few yards at most from their bounding surfaces, the formations of different ages are unequally indurated,—the oldest being by far the most consolidated, while the newest appear but little harder than the analogous deposits which at this day are known to be produced in freshwater lakes, at the mouths of rivers, on the sea coast, or on the bed of the ocean.

This may be satisfactorily proved by a short comparison of the three principal varieties of stratified rocks, viz. arenaceous, argillaceous, and calcareous beds. In the tertiary series loose sands not only occur, but, in fact, constitute a large part of the whole series in Europe; for the sandstones of Fontainbleau, and the "greyweathers" of the Wiltshire downs, and the molasse of Switzerland, seem only exceptions to the general rule. Clays abound under London, in Hampshire, and the sub-Apennine hills; and even the limestones, as the stony crag of England, the Leitha kalk of Transylvania, and the calcaire grossier of Paris, have a softness and looseness of texture not common in strata below the chalk. (Some freshwater beds in the Cantal, and near Weimar, are hard.)

In the oolitic system there are still some beds of sand, but sandstones predominate; there are also clays, but they grow denser toward the lower or lias formation; and the limestones exhibit the same gradations. In these respects the saliferous system differs but little, and still shows clays and sands and soft limestones; among the carboniferous rocks we lose almost totally the trace of loose sands, and soft clays (until brought to the surface) and the limestones acquire that compact and solid character which belongs to almost all the strata below the old red sandstone. Below the silurian rocks the induration of the strata is rapidly accelerated; the clays have become slate, the sandstones are changed to quartz rocks, and the limestones have undergone an equal metamorphosis. The superior consolidation of the primary strata has struck every intelligent observer, and, allowance being made for difference of materials and local igneous agency, there can be no doubt of the justice of referring this quality to the higher degree in which they have been influenced by general subterranean heat.

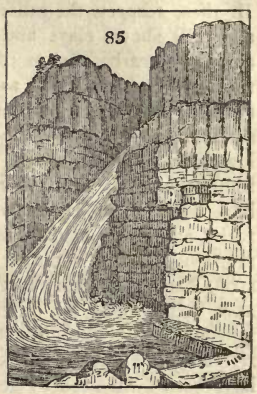
Alteration of the Structure of Rocks by Heat.

The influence of heat in altering the structure of rocks is no less decided than in condensing their substance. For by this agency the original stratified arrangement of rocks is greatly obscured, and in some cases almost wholly extinguished, while entirely new structures are introduced to supplant those formerly imparted by water. The general character of the divisional planes in rocks has been already noticed*; it is desirable, however, to extend the description formerly given of slaty cleavage, the most striking and important of all these structural changes. We shall previously give some illustrations of the evidence on which some geologists have attributed these effects to subterranean heat, and others to electrical currents.

A case which has fallen under our own observation

* Vol. I. p. 65, &c.

at the celebrated waterfall called the "High Force," in the upper end of Teesdale, Yorkshire, will first require attention. At this romantic spot the river Tees dashes down a precipice of 69 feet, which to the artist shows two distinct forms of rocks: the upper part is boldly prismatic, and the lower part stratified. Across the prisms run bands of stratification, and to the hasty observer this will appear a case of stratified basalt. But careful inspection demonstrates a more curious truth. The annexed sketch (taken from the Illustrations of the Geology of Yorkshire, vol. ii. pl. xxiii.) will explain the peculiar circumstances alluded to.



a. Basalt, rudely prismatic, grey with lichen.
b. Thin "plate," not very much indurated.
c. Bed of plate, *sub-prismatic.*
d. Beds of plate, *laminated.*
e. Thin limestone bed with a superficial layer of pyrites.
f. Bed of hard pyritous limestone.
g. Several beds of common dark limestone, with white shells and corals.

Here we see a new structure, commonly found in great masses of igneous rocks, communicated to the adjoining strata; but this is not very obvious in Teesdale, except where the basaltic rock is in very great quantity and thickness. At a distance from the heated rock, the shale or "plate" resumes its usual divisional surfaces, caused by nearly vertical joints which cross and intersect in rhomboidal or rectangular figures. (Compare cuts No. 86. and No. 87.) Both of these differ from those produced by the local application of heat, but neither of them is the effect of violent disturbance; both arise from the condensation of the matter of the strata, under the influence of heat or other causes competent to induce particular arrangements,—prismatic,

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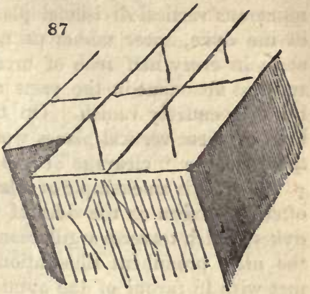

cubical, rhomboidal, &c., according to the nature, thickness, and position of the rocks, the degree in which the polarities of their particles are controlled by the different qualities of neighbouring mineral masses, and other important circumstances. Another case which also fell under the author's notice at Coley Hill, near Newcastle, appears strongly to confirm the view here presented, and at the same time to remove part of the obscurity which has always been supposed to overhang the origin of the "cleavage" of slate (see Vol. I. p. 67, &c.). In the annexed cut,

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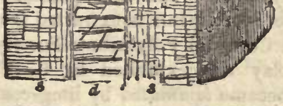

d, is a basaltic dyke, nearly vertical, and between twenty and thirty feet across, ranging east and west, and appearing at the surface.

s, is the ordinary coal shale, which is, as usual, very much laminated at a moderate distance (a few yards) from the dyke, and contains fern leaves and other plants between the laminæ.

At the sides of the dyke the horizontal lamination is obscured, the shaly mass is indurated, and traversed by numerous vertical divisional planes parallel to the faces of the dyke, most numerous near the dyke, so as to occur in every half inch of breadth, but becoming less and less abundant in the parts removed from the dyke, till they entirely vanish. On the surface section, the lines of these vertical planes would, on a minute scale, represent the "cleavage" edges of slate.

This fact is an example of a large class of phenomena, often to be seen on the sides of basaltic and porphyritic dykes, which traverse argillaceous strata; and it is one of the most prominent illustrations which we have ever met with in favour of the opinion that the cleavage of slate is a metamorphic structure produced by the action of heat. Heat, however, is certainly not the only agent for generating cleavage.

We are acquainted with instances in which a similar structure (though certainly less perfect) is found parallel to, and limited to the region of, great fractures of the strata where no dyke of basaltic or other pyrogenous rocks occurs. This is seen in limestone cliffs which border the north side of the Great Craven fault in Yorkshire, where it crosses Giggleswick Scar, near Settle, and certainly no igneous action is otherwise indicated or probable there.

Mr. R. Fox, in prosecuting his curious researches regarding the changes effected in metallic bodies by electrical currents, has been conducted to an unexpected result, which appears to be of importance in reasoning on the laminated structures of mineral masses generally, and especially on the "cleavage" planes. The following notice of the experiments is extracted from the Report of the Royal Cornwall Polytechnic Society for 1837.

"Some clay was exhibited by R. W. Fox, esq., which had become *laminated* by long-continued voltaic action, so as to resemble clay slate in its structure.

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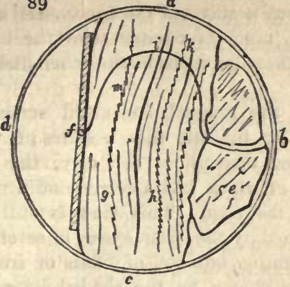

"The above figure may serve to illustrate the process by which this was accomplished. Let *a b c d* represent the top or rim of an earthenware cup or basin; *e*, a piece of copper pyrites; *f*, the upper edge of a plate of zinc; *i*, copper wire by which the two latter were connected; and *g*, *h*, the top of a mass or wall of clay between the copper ore and the zinc, and forming for each of them a watertight cell. The cell containing the copper ore was filled with a metallic solution — the sulphate of zinc, for instance — and the other with water mixed with a little sulphuric acid. The water with which the clay was worked up was also acidulated. Thus circumstanced, the apparatus was set aside three or four months, and was not disturbed till some little time after the water had evaporated, and the clay had become perfectly dry throughout.

"It then exhibited, on breaking off a portion of its upper part, lines of cleavage of a schistose character, parallel to the sides of the clay and plate of zinc, or at least as nearly so as was consistent with their undulatory form. In other words, the lines or laminæ were at right angles to the direction of the electrical forces.

"They are indicated by the lines on *g*, *h*; and the strongly marked line *a c* represents a principal line of division which separated the clay into two portions from the top to the bottom.

"These seemed to form, as it were, two voltaic plates, in opposite states of electricity, and one of them, consequently, more favourable than the other for the reception of metallic deposits and other bases from their solutions.

"Indeed, the general laminated structure of the clay appears to indicate that a series of voltaic poles were produced throughout the clay, the symmetrical arrangement of which had a corresponding effect on the structure of the clay. This view is still more strikingly confirmed by the occurrence, in several instances, of veins, or rather laminæ, of oxide of iron, the edges of which are shown by the shaded lines *k, l, m.* In these cases sulphate of iron was substituted for sulphate of zinc; and laminæ of oxide of copper were sometimes formed, in like manner, when a solution of that metal was employed; and moreover, numerous minute insulated portions or specks of the oxide of copper were detected in different parts of the mass of clay when broken."

These facts appear highly favourable to the opinion that the direction of cleavage planes in slate depends on *some form* of electrical excitement, and currents of electricity passing in given directions; but they do not at all negative the probability, from other and more general facts, that it is to the application of heat that the electrical currents owed their origin. In fact, when we remember that it is only among dislocated primary strata that real clay slate occurs, and that it is only in the vicinity of pyrogenous rocks, or fractures of the strata, that rocks of later date assume, however imperfectly, the slaty aspect, and that dislocations of the strata with unequal conducting powers for heat and electricity necessarily generate electrical disturbance and currents to restore the equilibrium, we see that the general opinion which geologists had adopted, of the dependence of the directions of cleavage and other symmetrical structures in rocks, upon local or general application of heat, may be very correct, though certainly it is incomplete. Mr. Fox's experiments will doubtless be repeated in other forms, but their present value is great, and they may, as he suggests, lead to practical results of value in mining operations.

We must, however, add some further details of the phenomena of cleavage, and discuss their bearing on another hypothesis, which ascribes to *pressure* this beautiful superposition of structure.*

The occurrence of cleavage *at all* in any given district is in some degree dependent on the nature of the rocks therein. Still more obvious is it that perfect examples of it only occur in certain argillaceous deposits. In a country consisting of alternations of thick argillaceous beds with coarse conglomerates, hard sandstones, limestones, quartz rock, and felstone, or greenstone, we shall find the cleavage, after passing through the argillaceous bed, more or less constantly interrupted by the other strata, — through which, however, a certain fissility, occasionally twisted and otherwise modified, is often traceable.

We have also for many years observed a beautiful case of the *bending* of the cleavage surfaces when they pass from one bed, or part of a bed, to another bed or mineralogically different part of a bed. Mr. Sharpe also admits this fact. This bending is always in such a manner as to render the angle of intersection between the cleavage and the stratification more acute, just as sometimes happens when a mineral vein crosses obliquely a strong throw, or when strata rise with an uplifting fault. The law is the same in all cases. These phenomena deserve the utmost attention from those who speculate on the theory of cleavage.

Beyond these completely or partially interrupting layers the cleavage recurs in the next band of argillaceous rock, with planes parallel to those first observed.

There are, however, cases in which alternating beds

* Consult on this subject, besides Memoirs by the Author, (Geol. Trans. 1820, and Brit. Assoc. 1843), and Professor Sedgwick (Geol. Trans. 1835), the later writings of Sharpe, (Proceedings of Geol. Soc. 1847. 1849), and Hopkins (Phil. Mag. &c.) See also De la Beche, in Geol. Observer, 1851.

of more and less argillaceous rock manifest cleavage, but not in parallel planes, and when this happens, the angular difference of the planes is such that those in the

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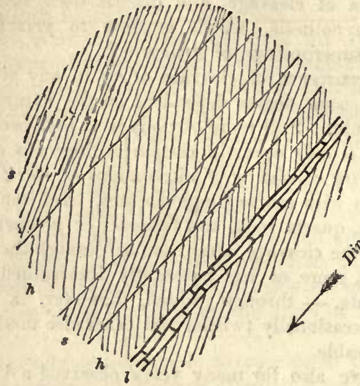

finer grained or more argillaceous bed meet the planes of stratification at more acute angles than those do which traverse the coarser and more sandy or more indurated bed. An example of this in secondary cleavage ("bate") is given in the author's paper on Craven rocks (*Geol. Trans.* 1828). He has since collected examples more obviously dependent on the difference of the mineral quality of the adjacent beds. Mr. Sharpe has admitted this peculiarity (*Geol. Proc.* 1848).

The above diagram shows a remarkable case observed in old red sandstone near Cork, (1843); *s* being soft red marly beds, *h* harder beds, *l* a laminated sandstone without cleavage, but jointed.

Another of the characteristic phenomena of cleavage was frequently presented to us, while surveying (in 1839) the Palæozoic strata of North Devon. Surfaces of stratification are usually found to be ridged and furrowed by the edges of cleavage, in such a way that the

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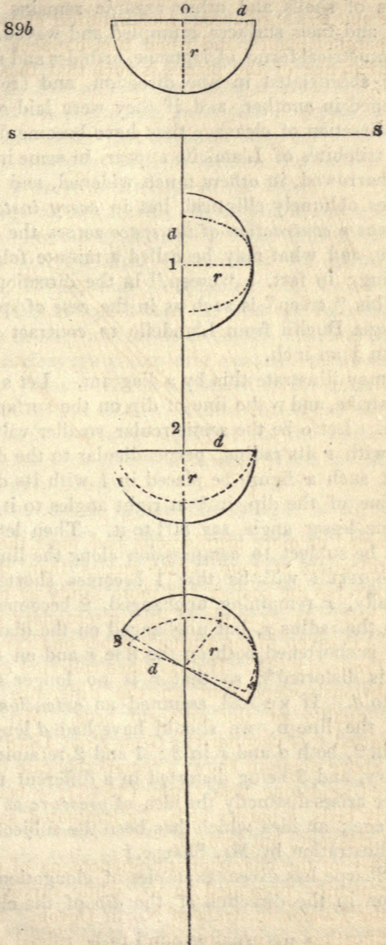

outlines of shells and other organic remains are distorted, and their surfaces crumpled and waved. Thus the symmetrical forms of leptænæ, orthides and spiriferæ become abbreviated in one direction, and (relatively) lengthened in another, and if they were laid obliquely to the direction of cleavage they have become distorted. So the trilobites of Llandeilo appear, in some instances, much narrowed, in others much widened, and in other instances obliquely elliptical, but in *every instance* the result was a *contraction of the space* across the edges of cleavage, and what may be called a minute folding, or furrowing; in fact, a "creep," in the direction of the dip. This "creep" is such as in the case of specimens of Ogygia Buchii from Llandeilo to contract them $\frac{1}{4}$ and even $\frac{1}{2}$ an inch.

We may illustrate this by a diagram. Let S S be the line of strike, and D the line of dip on the surface of the stratum. Let O be the semicircular smaller valve of an orthis, with *r* its radius, perpendicular to the diameter *d*. Let such a figure be placed in 1 with its diameter in the line of the dip, in 2 at right angles to it, and in 3 at some lesser angle, say 50° to it. Then let all the stratum be subject to compression along the line of the dip, the result will be that 1 becomes shortened diametrically, *r* remaining unchanged, 2 becomes shortened on the radius *r*, but unchanged on the diameter *d*, while 3 is shortened both on the line *r* and on the line *d*, and is distorted*, so that *r* is no longer at right angles to *d*. If we had assumed an *extension* of the rock in the line D, we should have had *d* lengthened in 1, *r* in 2, both *d* and *r* in 3; 1 and 2 retaining their symmetry, and 3 being distorted in a different manner.

Hence arises distinctly the idea of *pressure* as a cause of cleavage; an idea which has been the subject of elaborate illustration by Mr. Sharpe.†

Mr. Sharpe has given examples of elongation due to expansion in the direction of the *dip* of the cleavage;

* Brit. Assoc. Reports for 1843.
† Geol. Proceedings, 1847, 1849.

but it does not yet appear that any change of dimensions can be shown in the direction of the *strike* of the cleavage. No one can doubt that here we have indications of exact mechanical laws, operating on masses of matter, so regularly as to emulate the results of crystalline force on the molecules. But the latter force is *free* to arrange molecules singly by polar attractions, the former is *constrained* to obey certain axes in the mass.

Cleavage is remarkably developed in some districts which are formed upon one or more axes of anticlinal elevation and synclinal depression: for example, in Cumbria, Wales, and Devonshire. In each of these cases the fact is patent that the cleavage runs for 20 or 30 miles in one continuous direction, which is observed by all the cleavage planes over a considerable breadth of country. This direction is parallel to the great axes of movement in that district, almost exactly so on a great scale, though deviating slightly from the strike of the beds in particular places, especially when the strata are in any degree twisted.

The cleavage is in fact but little, if at all, affected by small irregular twists of the beds, and is, on the whole, more regular in its strike than they are. It is related to the great axes, not to the local bedding. May we from this infer that the general pressure on the axes of movement has been a determining cause of the new structures parallel to these axes?

Another thing is remarkable. The cleavage is less frequently vertical than inclined at a high angle, say 70°. It is also found at 45°, 30°, 20°, and even at much lower angles. Most frequently, when the strata are much inclined, the cleavage is inclined still more; but this has exceptions.

As the cleavage strike is not really dependent on the strike of the beds at a particular place, so is its dip not really dependent on the dip of the strata there: there may be more than one anticlinal and synclinal of strata (besides minor folds) and yet only one cleavage system.

According to Mr. Sharpe, a cleavage system may be regarded as bounded by parallel lines along which the cleavage is vertical, and in all intermediate points less than vertical, in the middle of the space horizontal or nearly so; and he imagines these cleavage surfaces to be portions of great curves, everywhere perpendicular to pressures emanating from the axis of that space; that is to say, they would be so many parts of cylindrical sheets of uniform tension.

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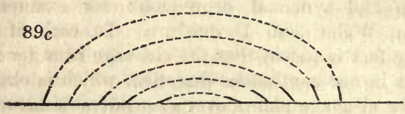

Upon this view we are not perhaps obliged to take into account any one of the axes of *movement* in a district, but the *pressure on a whole district;* and we are even released from referring the slaty cleavage to the date of their axes; it may be posterior to them all, and be only related to a general subterranean cause, of which they are some of the external manifestations.

A curious investigation of the component parts of non-fossiliferous slates has convinced Mr. Sharpe that the parts of such rocks have undergone that compression across the planes of cleavage, and extension in the direction of the dip, which had been inferred for other slates from evidence of altered fossils.

On the foundation of facts which have thus brought out the idea of internal pressure as an antecedent to the production of cleavage, Mr. Hopkins* has endeavoured to point out the accurate mechanical conditions of the problem, and to indicate the points to which the attention of future observers should be specially directed for the purpose of ascertaining the data required for a complete theory. Though we cannot here give an analysis

* Camb. Phil. Trans. 1847.

of this investigation, a short statement of the bearing of it may suffice to put geologists on the right track for further inquiry, and perhaps to show them how much of beautiful illustration of geology is lost by those who permit themselves to be deterred by mathematical expressions from a close survey of physical truths. *Pressure* and *tension* being taken as of opposite meanings, and coexistent in a mass of rock, we may admit as representing their *directions* three coordinate axes passing through a central point at right angles to each other. Along these axes the effects of pressure and of tension will be direct and total, so that a small plane situated at right angles to one of these lines will be subject to the pressures or tensions of that line only, and will be moved, if at all, along that line; but a small plane placed in some other position will be moved in a line not having the same direction. As these pressures and tensions are assumed to be *general*, and so to affect all the particles, it is obvious that we shall have three coordinate *planes*, parallel to which direct forward or backward motion is possible, and between them other (tangential) planes in which the possible motions are oblique.

Now in the case before us one of the axes of direct pressure or tension may be regarded as of little or no effect, viz., that which coincides with the strike of the cleavage and the strike of the strata. And from this it follows, that *direct* motion from pressure should take place along lines lying in one plane only, viz., that which is perpendicular to the anticlinal, and only in two directions crossing each other at right angles in this plane, — one of these directions being that of pressure, the other that of tension. Planes perpendicular to these two lines will be planes of direct tension or pressure, and their strike will be that of the beds. There will be also crossing these planes (but having the same strike with them) two other (tangential) planes, making with them angles of 458, but with each other angles of 90°, in which oblique motions will be at a *maximum.* One of these (tangential) planes, therefore, will *dip* in the same direction (but not necessarily at the same angle) as the beds, and the other in the opposite direction.

These things premised, we may by referring the pressures to the plane of stratification discover their effect on the outlines of organic remains, which, for the sake of comparison with our observations already recorded, we shall assume to be semicircular, and always laid with the hinge or diametral line parallel to the line of dip.

First, let it be supposed that *pressure* is applied perpendicular to the stratification and tension produced parallel to the strata. In this case there will be a symmetrical extension of the figure in the direction of the line of dip. If *tension* be applied perpendicular to the strata and pressure exerted parallel to them, the semicircle will be symmetrically contracted to a semiellipse, as in the example already represented in the diagram (p. 119.); and, finally, if either pressure or tension be applied in a direction meeting the plane of stratification at 45°, so that a plane of maximum tangential action shall coincide with the stratification, the semicircle will be unsymmetrically changed in form, so as to become elliptical with its diameter lying obliquely across the line of dip — in fact, to be *angularly distorted.*

When, therefore, angular distortion occurs in an equilateral shell placed symmetrically with respect to the line of dip, we may be sure the result is due to the tangential movements developed by pressure. If this happens chiefly or exclusively when the cleavage nearly coincides with the stratification, and happens rarely or not at all when the cleavage meets the strata at or about an angle of 45°, we may conclude that the cleavage plane is not perpendicular to any axis of antecedent pressure or tension, but is coincident with one of the two planes of maximum tangential movement.

Thus a delicate and critical inquiry is opened out for geologists who may have been trained to the accurate use of graduated instruments.

Metamorphic Rocks.

For the application of the useful term, "Metamorphic Rocks," in the description of phenomena connected with the occurrence of igneous rocks, and reasoning on their causes, we are indebted to Mr. Lyell; and there is, perhaps, no part of the study of ancient nature more worthy of attention from philosophic minds. For thus, and thus only in many instances, are we enabled to arrive at probable and intelligible views of the course of changes which even the most solid materials of the globe have undergone. The Pythagorean maxim,

"Nihil est toto quod perstet in orbe,"

comes into full credit when we approach the great masses of felspathic and augitic rocks which have been effused in a melted state above and amongst the ordinary products of water. As we pass from the districts where no igneous rocks appear at the surface, towards the mountain regions where they abound, the strata acquire hardness, assume new structures, and in their innermost texture and substance appear under new and peculiar aspects. In order to trace these phenomena, so that the picture may not only be interesting but instructive, it will be necessary to distinguish the effects which we call "metamorphic" into three classes.

1. There are rocks which, by the local influence of heated rocks, are *locally* changed as to the arrangement of their mineral ingredients; so that earthy substances become crystalline; and the view thus arising is capable of being *generalised* so as to explain the corresponding appearances of similar rocks, by a similar but more general cause.

2. There are stratified masses which have undergone,

near pyrogenous rocks, a *loss* of some portions of their substance.

3. There are cases in which the rocks near igneous dykes have not only been hardened, fissured in a certain manner, and subjected to re-arrangement of their ingredients; but further, there have been introduced into their substance, *minerals* not known in the same rocks elsewhere. This is also found to have a general application to rocks exhibiting like phenomena, but upon a scale so vast as to require the supposition of very general application of heat.

From these facts and inferences we pass immediately and inevitably to the great geological problem naturally arising out of such data, viz. the degree in which the peculiar mineral characters and admitted absence of monuments of organic life among the oldest strata are to be relied on as conclusive testimony concerning the primeval condition of the globe.

Re-arrangement of the Particles of Rocks.

One of the earliest notices of an extensive mass of limestone changed by the action of igneous rock, is that of the district of Strath in the Isle of Skye. Dr. Macculloch's observations in this island led him, in 1816, to believe that certain laminated shelly limestones, which occupy a considerable breadth, and cross the island from Broadford to Loch Slapin, are altered in various ways, by contact with and proximity to sienitic rocks, so as, in a considerable space of country, to have lost all stratification, and in some instances to have assumed the character of a pure white marble of fine grain. In its chemical composition it is generally a pure carbonate of lime; but where in contact with the sienite or the trap veins, becomes overloaded with silica, magnesia, and argil. In such situations it often contains veins and nodules of greenish transparent serpentine, and appears in a variety of colours, grey, dove-colour, dark blue, grey, striped, mottled, veined, pure white. At points removed from the sienite, the pectines, and other shells which this rock contains, and its position with regard to other secondary rocks above and below, have satisfied not only Dr. Macculloch, but Mr. Murchison and professor Sedgwick, that it is a part of the lias formation, which also occurs in Pabba, &c.

A case of the same kind, on an equally extensive scale, which occurs in connection with the "whin sill," or stratiform basalt of High Teesdale, especially in that portion of the country where the trap rock is very thick, has been made known by Professor Sedgwick. The limestone of this district, both above and below the basalt, is usually of a very dark grey or even blackish colour (some beds are very black); but in contact with that rock it loses its obscure blackness (probably by loss of bitumen), becomes of a clear blue tint, and finally, the change being complete, of a clear or greyish white. The arrangement of the particles is altered in an equal degree. The stone usually is compact, or partially varied by laminar shells, or crystallised plates of calcareous spar, representing the stems of crinoïdea. Near the "whin" these characters change; the stone becomes granular and crystalline (in the sense that statuary marble deserves this term), and in some cases the crystalline grains separate by disintegration of the mass. In these metamorphic limestones small cavities sometimes occur; but the most interesting fact that remains to be noticed, is the occurrence of crinoidal columns in the midst of the granular crystalline mass (our own observation). They are, however, not common. These phenomena may be seen over some square miles of surface in the vicinity of the High Force and Caldron Snout, chiefly, perhaps, in the limestone which overlies the basalt.

In connection with the ancient volcanic rocks of the Kaiserstuhl mountain (in the Rhine valley), limestone of the Jura formation (or oolitic system) is similarly altered to a really crystallised mass of calcareous spar;

and, in addition, mica and other minerals are intermixed with the limestone. The broad flakes of carbonate of lime are here very remarkable.

The basaltic district of Antrim furnishes abundant and precise evidence of the conversion of chalk into granular marble by the action of basaltic dykes.

"The Irish chalk is seldom of a texture sufficiently loose to soil the hand; and in the few instances where this does take place, it is in a very slight degree: its general colour is either perfectly white, or white with a very slight tinge of yellow; towards the lower part it passes into a uniform ash-colour; the texture then becomes still more compact." "At many points near Belfast, Glenarm, Moira, &c., the chalk is frequently traversed by basaltic dykes, and often undergoes a remarkable alteration near the point of contact; where this is the case, the change sometimes extends 8 or 10 feet from the wall of the dyke, being at that point greatest, and thence gradually decreasing till it becomes evanescent. The extreme effect presents a dark brown crystalline limestone, the crystals running in flakes as large as those of coarse primitive limestone; the next state is saccharine, then fine grained and arenaceous; a compact variety having a porcellanous aspect, and bluish grey colour succeeds; this towards the outer edge becomes yellowish white, and insensibly graduates into the unaltered chalk. The flints in the altered chalk usually assume a grey yellowish colour; the altered chalk is highly phosphorescent when subjected to heat." *

In the island of Raghlin, directly over against Kenbaan Head, a singular combination of dykes occur (seeming to be a continuation of those which at the latter place have been attended by such extraordinary disturbances). Here, within a distance of 90 feet, these dykes may be seen traversing the chalk, which is converted into a finely granular marble, where contiguous

* Dr. Berger on the Geological Features of the North of Ireland, Geol. Trans. vol. iii. p. 172.

to the two outer dykes, and through the whole of the masses included between them and the central one.

The following diagram, copied from Mr. Conybeare's section (*Geological Transactions*, vol. i. pl. 10.), will be useful for reference. It represents the ground plan of the dykes as they appear on the shore.

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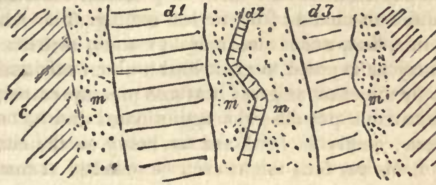

d 1. Dyke, 35 feet wide. *d* 2. Dyke, 1 foot wide.
d 3. Dyke, 20 feet wide. *c*. Chalk.
m. Granular marble.

One of the most direct objections to that part of the Huttonian system of geology in which the induration of rocks is attributed to the action of heat, was drawn from the calcareous strata, which, it was said, would have parted with their carbonic acid, and thereby have ceased to be limestone. That such an effect would take place in the open air, in the ordinary state of limestone (not perfectly dry), is a matter of invariable experience; but Dr. Hutton, with his accustomed sagacity, proposed the hypothesis that the carbonic acid gas would not be liberated by *heat under great pressure*, such as the weight of the ocean pressing on its bed. This hypothesis, sir J. Hall, with equal sagacity, put to the test of accurate and conclusive experiments. In the breech of a gun-barrel he placed an earthen tube half filled with calcareous matter in powder, and strongly compressed, the rest of the space being filled with powdered silica. The tube was then closed hermetically by a mixture of fusible metal. The end of the barrel where the powdered earth was, being heated in a furnace, a part of the fusible metal yielded to the heat, and came nearly into contact with the porcelain tube (separated by aqueous vapour and air); the rest remained solid.

After the heat had been sufficiently applied, and the whole had become cool, the fusible metal which stopped the tube was melted out by moderate heat, and the calcareous powder in the porcelain tube was examined. Similar experiments were made in porcelain tubes alone, with different modes of hermetical sealing. The general result was, that, under mechanical pressure, carbonate of lime may be exposed to great heat without calcination; while, by the effect of great heat and pressure combined, the calcareous powder was agglutinated into a solid limestone, nearly as hard and as heavy as the natural rock. Some portions might even be polished as marble.

By a mechanical contrivance, the degree of pressure on the materials exposed to heat was varied and measured; and it appeared, that with a pressure of 52 atmospheres, equal to a column of 1700 feet of sea-water, powdered limestone was converted to hard stone; with 86 atmospheres, equal to a column of 3000 feet of sea-water, it is changed to marble; with a pressure of 173 atmospheres, equal to a column of 5700 feet of sea-water, it is completely *fused*, so as to act strongly on other earthy substances.

The celebrated marble of Carrara is probably an altered limestone of the oolitic era.

Having now seen many examples of the conversion of common limestone into crystalline marble, both by actual experiment, by volcanic action, and the heat communicated from pyrogenous rocks of different kinds, the application of these truths to the history of the "Primary Strata" is obvious. For primary limestones differ from secondary and tertiary calcareous deposits merely by their mode of aggregation, which is not such as water ever produces in carbonate of lime, but is exactly comparable to that occasioned by heat. And this general analogy is strengthened by collateral circumstances, as, for example, the frequent occurrence of serpentine in some of the "primary" limestones is a fact exactly parallel to the introduction of serpentine among the crystallised metamorphic limestone of Skye (noticed by Macculloch). In Radnorshire, Mr. Murchison observed the ramification of serpentinous strings through limestone which was otherwise altered in contact with a felspathic trap; and in this and other places, anthracitic coatings and nests, and crystals of copper and iron pyrites, complicate the effects. In one place, a serpentinous rock of this kind is 20 or 30 feet wide. If therefore, in conformity with so many and such strong analogies, we admit the inference that the crystalline primary limestones have acquired this character by the action of heat, it must follow that this heat was of a very general, if not universal, application below the primary strata, for there is, perhaps, no considerable district known where the gneiss and mica schist systems are devoid of such crystalline limestone, and the occurrence of it is not specially connected with the local appearance of igneous rocks. This important inference will, however, be invested with a higher degree of probability if it be also found, as a matter of fact, that the other strata with which this limestone is associated show independent signs of having been subjected to a general heat.

Alteration of the Chemical Nature of Rocks.

One of the most popular of all the proofs of the pyrogenous origin of basalt and greenstone, is the effect they produce on coal and bituminous shales, for by their action the coal is often turned to coke, and the dark shales assume a very light colour. These effects are almost too common in Scotland and the North of England to deserve especial notice. Thus the Kyloe dyke, which crosses the Tweed below Lennel, has converted the coal-seams intersected by it into a sort of cinder, the bituminous matter having been entirely dissipated. (*Milne on the Geology of Berwickshire.*) Several of the dykes in the collieries of Newcastle and Durham (as the dyke in Walker colliery, the Coley Hill dyke, the Cockfield fell dyke, &c.) have expelled the bitumen from the coals and shales, to various distances, according to the width of the dykes, and other less known conditions of the adjoining strata. The anthracite has in some instances been injected into the cracks of neighbouring sandstones. Analogous facts on a smaller scale are found in connection with the trap dykes in Radnorshire, &c., which are frequently accompanied by anthracitic nests and coatings.

The following notice of the effects of the remarkable Cockfield dyke is from an eye witness, whose observations were communicated to me by my friend John Ford, esq.

"In working the coal towards the dyke, when within 50 yards of it the coal begins to change. It first loses the white spar in its joints and faces; looks dull, tender, and short; and loses its quality for producing flame. Nearer the dyke it has the appearance of half-burnt cinder: still nearer it decreases in thickness, and becomes a hard cinder 2 feet 6 inches thick. Eight yards from the point at which the coal becomes a real cinder, that is, 8 yards nearer the dyke, the coal assumes the appearance of soot caked together; it is called 'dawk' or 'swad:' when it touches the dyke, the coal is reduced from 6 feet to 9 inches."

"On each side of the dyke, betwixt it and the regular strata, there is a thin layer of clay, or, as it is called, a 'gut' or 'core,' about 6 inches thick, which turns the water from the rise to the dip side of the dyke, and forces it to the surface in several springs, in the direction of the dyke, where it crosses the country." The damage done by the dyke is thus estimated: "25 yards of tender, short, spoiled coal; 16 yards of cinder; and 10 yards of dawk or swad," making a total of 100 yards of spoiled coal throughout Cockfield fell. The dyke is nearly vertical, and 18 yards in width; the strata of coal, sandstone, &c. are dislocated by it about three fathoms. In other situations the "throw" is greater.

The application of these facts to the explanation of the condition of ancient strata is important. For it is a general fact, that the carbonaceous substances which are associated with any part of the primary or transition strata, are of the nature of anthracite, which is devoid of bitumen. Whether it will be proper to extend this explanation to the large anthracitic beds of Pennsylvania, South Wales, Devonshire, Brittany, &c., some of which lie among secondary strata, is at present uncertain.

Dolomitic Limestone.—One of the effects of the sienite of Skye, in contact with the lias limestone, which it converts to fine granular marble of many colours, is the introduction of silica, alumina, and *magnesia*, into its composition. (Macculloch, *Geol. Trans.* vol. iii. p. 42.) This sienite is principally a felspathic mass, varying from claystone to clinkstone and compact felspar, from which no transfer of magnesia could be supposed. Von Buch, in the course of his extensive and laborious examinations of plutonic and volcanic rocks, was led to attribute to a rock of quite another kind, the melaphyre (black or pyroxenic porphyry) of the southern flank of the Alps, not only an important function in the elevation of mountain ranges like the Alps, but the peculiar chemical and mineral change which is locally noticed in some of the limestones. By this change carbonate of lime becomes a double carbonate of lime and magnesia ; the compound is crystalline, and often of a dazzling whiteness. This is the case with the dolomite of St. Gothard, and with much of that which occurs on the Lago Lugano.

This last is the vicinity to which Von Buch has specially directed the attention of geologists, and as melaphyre, granite, dolomite, and common limestone here occur in abundance and in varied circumstances of exposure, perhaps no better locality can be chosen for investigating the truth and applicability of the opinion of this eminent geologist.

Between Varese and Tresa is seen the section presented below. In this section the main facts commonly

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1. Gneiss. 2. Mica schist. 3. Granite. 5. Melaphyre.
6. Tuff. 8. Sand and gravel. 9. Limestone. 10. Dolomite.

noticed as to the association of melaphyre with the other rocks are well typified, and it is seen that the occurrence of dolomitic limestone is not *uniformly* connected with the appearance of melaphyre; sometimes it adjoins granite, in other localities mica schist: it also appears that limestone is not always dolomitised in contact with melaphyre, or granite; and those geologists who have imagined that Von Buch supposed there was a real transfer of carbonate of magnesia from the augitic rock, have very naturally arrived at the inference that this district lends no countenance to the speculation. But we learn from M. Elie de Beaumont (*Ann. des Sc. Nat.* vol. xviii.), that this was not Von Buch's meaning, and indeed, that would easily appear from the facts quoted by him in support of his opinion. The true notion advocated by Von Buch, of these transformations of limestone, is that the eruption of melaphyre was coincident with violent disturbances and fractures of the country in a particular line parallel to the melaphyre; and that along the fissures then produced, gaseous sublimations of different kinds found their way to the surface, and altered particular rocks in their passage. The ordinary and obvious form of objection above noticed therefore fails; and it remains to be seen whether the occurrence of dolomite in definite relation to lines of melaphyre, or, to take the problem in a still more general sense, to fractures of the earth's crust, is a circumstance well proved; and if so, whether the sublimation of carbonate of magnesia would be chemically probable. On this latter subject, Dr. Daubeny and Dr. Dalton stated facts in confirmation of the view of Von Buch (*Reports of the British Association,* for 1835), and on the former question, we have related, in describing the geology of Yorkshire, the dolomitisation of common limestone by the sides of faults and mineral veins, far away from igneous rocks of any kind. It seems, therefore, unsafe to reject Von Buch's remarkable hypothesis, without a patient investigation of many collateral points; and, on the other hand, the dolomitic masses of Franconia, which form a part of the Jura kalk, and the magnesian limestones of England (extensive deposits which are unconnected with pyrogenous rocks), appear to show that subterranean heat is not the only nor the principal means of introducing magnesia as an ingredient of limestone. We may, indeed, choose further to suppose that the submarine springs, which probably gave origin to the magnesian limestones of Durham, were a consequence of that great disturbance of the earth's crust which is so manifest in the coal districts of England; and this easy and probable explanation for these cases, while it recognises the general principle which connects magnesian limestones with dislocations of the strata, may possibly be found applicable to other examples.

One of the points favourable to investigation of the relation of dolomitic limestones to volcanic forces, is Gerolstein in the Eifel, where, round a particular vent, for a considerable space, the "transition" limestone (corresponding exactly to the "Wenlock" limestone in the silurian system of England) is converted to dolomite, and appears in the usual unstratified, fissured, and antiquated forms of that rock, while further off it is a thin-bedded rock; organic remains occur in both the common and dolomitic limestone (observed 1829). To the facts which appear in this volcanic region, Von Buch appealed in proof of his hypothesis; but Dr. Daubeny

(*On Volcanos*, p. 51.), after describing the cellular character of the lava, and the way in which it is related to the present form of the surface, observes, "It seems difficult to reconcile the hypothesis of Von Buch with the age which we are compelled to assign to the volcanic operations here, as well as in other parts of the Eifel. As it is evident that no foreign ingredient could penetrate the substance of the rock in its present hardened condition, so as to unite with the other constituents, and diffuse itself uniformly through the mass, it seems necessary for Von Buch's hypothesis to suppose the limestone to have previously been at least softened by the heat, which occasioned the sublimation of the magnesia. Hence we should be obliged to fix the period at which this process took place as antecedent to the formation of the valleys, for these would be necessarily obliterated by any softening of the limestone which now overhangs them.

"Indeed it would be necessary to carry back this supposed softening of the calcareous rocks to some period antecedent to the retirement of the ocean, when sufficient pressure might be exerted to prevent the carbonic acid from being driven off from the limestone when exposed to the heat required for softening it.

"But all this is contradicted by the phenomena of the volcanic products in question, the cellular appearance of which plainly indicates the absence of pressure, and which even seem, from the existence in them of craters, and by the manner in which they have accommodated themselves to the present slope of the valleys, to have been formed since the commencement of the present order of things."*

Dolomitic limestone is not at all common among primary strata, though these early limestones often contain serpentine in strings and veins, augite (as at Tiree), mica, and other magnesian minerals.

Generation of New Minerals.

Perhaps no more interesting or satisfactory evidence of the generation of new minerals in strata which adjoin a "trap" rock has ever appeared than in the description of the great dyke south of Plas Newydd in Anglesea, by professor Henslow. (See Camb. Phil. Trans. vol. i.) The substance of this dyke is basalt, composed of felspar and pyroxene; its width is 134 feet, and it cuts perpendicularly through strata of shale and limestone. The strata on each side form an abrupt cliff, against the Menai shore, about 15 feet high, but the dyke, through decomposition, offers a gradual slope.

The *Plas Newydd dyke* crosses the Menai. The cliff which bounds the dyke at Plas Newydd is composed of clay shale, and argillaceous limestone. The lowest portion (thin calcareous shaly bed), on approaching the dyke, undergoes various changes. At 15 feet from the contact it forms a compact bluish grey mass, with spots of a fainter colour. In contact it is bluish green, very compact and hard. The shaly structure disappears, in a great measure, near the dyke (as at Coley Hill).

The next portion of the cliff, proceeding upwards, consists, at 50 feet from the dyke, of a soft dark-coloured plastic clay shale, thinly laminated. At 35 feet from the dyke this becomes indurated; at 10 feet it is a cherty mass, inclosing patches of highly crystalline limestone; in contact it is a hard porcellanous jasper of various colours. (Impressions *of shells* remain in it.)

The third division of the cliff consists of dark argillaceous limestone, which in contact is found of a speckled dull green and brown colour.

Above this is a thick body of clay shale, which, near the dyke, is partially turned to a flinty mass, while the rest of the shale assumes a confused appearance of crystallisation and globular structure. Perfect crystals are recognised in this mass of two distinct kinds, and exhibiting every gradation of aspect from a globular and concretionary to a perfectly crystalline character. Some of the crystals (analcime) have twenty-four trapezoidal faces. Shells of *brachiopoda* are enveloped in globules and crystals. Other crystals have twelve rhomboidal faces, and prove to be garnet of specific gravity 3·353. The crystals were examined by professor Cumming, and those of analcime analysed by him, and found to have a specific gravity of 2·293, or 2·394. Minute garnets in the form of rhombic dodecahedrons were found by the Rev. J. Harrison under the basaltic mass which overhangs the Tees, below Caldron Snout in Teesdale, in altered shale and limestone.

The segregation of mineral substances in rocks adjoining trap dykes is noticed by Mr. Milne, in his account of the geology of Dumfriesshire.

Since it thus appears that in many instances where the masses of igneous rock were considerable, perfect garnets have been produced by heat in the neighbouring sedimentary strata, though these were not in other respects re-crystallised, we turn with interest to the well known and general (though not universal) fact of the occurrence of garnets in the ancient strata of gneiss and mica schist, as a valuable addition to the evidence brought by the crystalline limestone associated with the same strata, in favour of the opinion that the whole mass of these rocks has been subjected to a pervading high temperature. For the occurrence of garnets in mica shist and gneiss is entirely unconnected with any local effect of heat derived from particular masses of granite, greenstone, &c.; nor can their occurrence be often accounted for by any supposition of their having formed part of more ancient rocks, which by disintegration yielded them to the watery currents concerned in accumulating the primary strata; for they are in general *perfectly crystallised,* among fragmentary scales of mica, and worn and broken felspar and quartz, or granular aggregates of those substances, scarcely differing in arrangement or aspect of the parts from particular sandstones and coarse argillaceous slates. The term so commonly employed of "crystalline schists," for mica schist, gneiss, &c., appears to be seldom justified by accurate examination; for frequently, we believe, the parts of these rocks are not individually *crystals* (as mica and felspar are in granite), *nor envelop crystals* (as quartz often envelops the other substances in granite), nor are in a state of *crystalline aggregation,* as the grains and plates of most primary limestone, but are parts of crystallised bodies fragmented and worn in various degrees, aggregated in laminæ under the influence of water (perhaps in a peculiar state), and subsequently consolidated, but not melted, nor re-crystallised, by the application of heat.

It is, however, thought by some geologists that the whole mass of the primary schistose rocks is to be viewed as metamorphic; as transformed from some other sort of sedimentary rock—grauwacke, for instance—and re-arranged into a *crystalline rock* of granitic aspect and affinity. We must therefore pay attention to some of the evidence which is adduced in support of this important hypothesis.

Metamorphic Slates.

As containing examples of metamorphic rocks, on a considerable scale, and of interesting if not remarkable variety, the district of the Cumbrian mountains may be advantageously quoted. In connection with the granite of the Caldew occurs the remarkable mass of chiastolitic and hornblendic slates, which form the base of the clay slate system of Cumberland; and it is thought that these rocks are, at least in part, metamorphic, similar combinations being found in analogous situations elsewhere. Dr. Macculloch ascribes a metamorphic origin to hornblende schist, viewing this rock as the extreme term of a series of changes commencing with clay or shale, and passing through siliceous schist or Lydian stone. Argillaceous schist, when in contact with granite, is sometimes (as in Shetland) converted into hornblende schist.

The hornblende schist of the Cumbrian granitic district is in places similar to that which adjoins the granite of Glen Tilt; and in each case its slaty structure is parallel to the crystalline faces of the prisms of hornblende. Some of this rock is almost pure crystallised hornblende; in other parts hornblende and felspar appear; but in Cumberland at least, and, judging from specimens, we think also in Cornwall, it is not quite correct to call another metamorphic rock gneiss. There appears to be produced, in connection with the granite of the Caldew, a combination (in small quantity) of crystallised mica and uncrystallised quartz, which has been called mica slate. The main fact to be attended to with regard to these phenomena of contact is, whether the parts of the altered rocks called gneiss, hornblende schist, mica schist, &c., are really *crystals,* and *in crystalline aggregation,*—circumstances often erroneously admitted with regard to primary strata, in consequence of the very inaccurate use of these important and characteristic terms.

In professor Sedgwick's account of the succession of the strata above the granite of the Caldew, given below, he seems to refer all the interpolated crystals of the upper part of the series to chiastolite. Some of the rocks appear, however, to be genuine hornblende slate crystallised, and one of our specimens is traversed by a granite vein.

Skiddaw slate.—Generally a fine glossy clay slate, much penetrated by quartz veins.

Crystalline slaty rocks:—

1. Skiddaw slate, with interspersed crystals of chiastolite, alternating with and passing into the preceding group.
2. A similar slate, with numerous crystals of chisatolite, passing in the descending order into a crystalline slate, sometimes almost composed of matted crystals of chiastolite.
3. Mica slate spotted with chiastolite
4. Quartzose and micaceous slates, sometimes passing into the character of gneiss.

Granite.—(White felspar, grey quartz, and black mica.)

A different series of changes may be traced among different rocks in Borrowdale and Wastdale, where the members of the middle division of slate rocks abut against the granitic mass which forms the base of Scafell, and occupies considerable breadths in Eskdale.

The slaty rocks alluded to are bedded and laminated; but besides the cleavage structure, which has been superadded, and which crosses all the beds of fine, coarse, and laminated grauwacke, we notice (as in the rocks which overhang the Bowder Stone) extreme induration, and the plentiful occurrence of spots and strings of epidote. In other beds the stratification remains, but the mineral composition is complicated by the segregation of spots of green earth, and nodules of green earth, calcareous spar, quartz, or even calcedony, so that the stone would, by most persons, be called amygdaloid. It is, however, a widely stratified rock, and passes by perfect gradation in Borrowdale, near Ulpha Park, on Grasmere, and in Patterdale, to the common bedded and spotted slate. On approaching yet nearer to the granitic mass, other changes appear; the slaty stone becomes very hard and compact, is traversed by abundance of fissures, acquires a peculiar spotting, which finally assumes the character of felspar, till the whole mass becomes what is often called clay porphyry, and at length can in no manner be distinguished from variolites and porphyries with a compact base. (Some of these rocks have been called greenstones.) This series of changes may be traced in a breadth of two miles, by walking over the summit of drainage between Borrowdale and Wastdale, called Stye Head.

What renders these alterations the more interesting, is the abundant occurrence of garnets of a fine red colour and perfect crystallisation (rhombic dodecahedron) in the porphyritic, partially porphyritic, and even brecciated rocks. Such specimens may be gathered on the slopes of the Gable Mountain, or obtained from the rocks near the summit of the pass of Stye Head (observed by the author 1838). How many of the porphyritic masses of this interesting region may hereafter be ranked as metamorphic slates, we cannot predict; but many rocks at the base of Helvellyn and in the Vale of St. John's (some of which contain garnets) appear to the author to deserve examination in this respect.

On a great scale, the alternation of porphyritic and schistose rocks in this region is established by professor Sedgwick's laborious researches, still only partially known to geologists. The results of his corresponding examination of the parallel series of rocks in North Wales appear very similar to those obtained in the Cumbrian mountains. (See *Geol. Proceedings,* vol. i. p. 400.)

The alterations produced upon the argillaceous slaty rocks of Cornwall, by the proximity of granite, are differently reported by different observers; but in general they appear to be inconspicuous, and perhaps cannot be described in a smaller compass than in the words of Oeynhausen and Von Dechen, who say,—"The killas is, at its junction with the granite, rather hornblende slate and greenstone than clay slate. The transition from clay slate into hornblende slate and greenstone is commonly so gradual, that we have not been able to trace any where a line of junction between both rocks." (*Phil. Mag. and Annals*, 1829.) The slightness of the changes which are remarked near many of the granite veins of Cornwall is not an unusual circumstance elsewhere, among argillaceous slates inclosing greenstones and porphyries; and perhaps the reason may be, that these substances *had already undergone great heat, and suffered a great degree of change from their first condition.*

Speaking with reference to the granite of Cligga point, and the porphyritic elvan courses of St. Agnes, the Rev. J. Conybeare observes,—"The killas, which is traversed and covered by these more crystalline rocks has, for the most part, the character usually ascribed to clay state, and its strata occasionally present singular curvatures; in many places it passes into chlorite slate, and in the immediate neighbourhood of these dykes it usually presents either a highly crystallised form of that rock, or such an intermixture of it with quartz and felspar as might fairly be esteemed a variety of gneiss." (*Geol. Trans.* iv. p. 403.)

Metamorphic Mica Schist, Gneiss, &c.

From cases like those already mentioned, where argillaceous slates, on approaching granite, appear in every intermediate state of change till they finally are converted to clay porphyry or to hornblende slate, we pass to consider other supposed transformations, in which the original substances are similar, but the product is different. Speaking of the altered rocks round Dartmoor, Mr. De la Beche (*Manual,* p. 479.) observes,—"The grauwacke slates in many parts of the country surrounding the granite of Dartmoor have suffered from its intrusion, some being simply micaceous, others more indurated and with the characters of mica schist and gneiss, while others again appear converted into a hard zoned rock strongly impregnated with felspar."

Von Dechen's account of the changes effected by the granite of the Hartz on the grauwacke of that region, appears not dissimilar to the description we have given of the Cumbrian rocks, for flinty slate, quartz rock, greenstone, &c. are stated to be the result of the igneous action. Mr. Griffith has found it convenient to express by a particular colour the metamorphic portion of the slaty series of the South-east of Ireland which surrounds the granite of Wicklow and Wexford. He describes them as "altered rocks in the neighbourhood of granite, clay slate, passing into greenstone or greenstone slate, or serpentine, or crystalline micaceous slate, or micaceous shining slate, or flinty slate." Similar phenomena are recorded by the same geologist, in a considerable breadth round the Mourne mountains. (See his Map, 1838.)

Von Buch first made known the interesting circumstances under which the syenite of Christiania touches and partially overlies the "transition" rocks of that country, which yield trilobites, orthocerata, &c. in considerable abundance. Mr. Lyell has recently explored this district, and, fully confirming the important inference of Von Buch, that the sienite was of posterior date to these transition strata, observed those changes which are now known to be the frequent concomitants of the contact of igneous and stratified rocks. The limestone, usually of very dark colour, is turned into white marble, the schist into Lydian stone, and "sometimes into mica schist," of which Mr. Lyell saw one striking example at Grorud, north-east of Christiania. *Traces of fossils* are not unfrequently discoverable in some of the crystalline and *altered rocks* of the transition formation, so that the actual conversion of the latter into metamorphic strata is unequivocal. (Lyell, in *Brit. Assoc. Reports*, 1837.) The rocks here termed syenite are considered by Mr. Lyell to be (geologically speaking) of the granitic family; they seem to pass into trap porphyry, and divide the gneiss and less ancient schists in a very irregular manner, but do not spread widely over them in any part of the district. Tabular masses of igneous rocks are no where seen to spread over the fossiliferous rocks, except where they have assumed the usual aspect and characters of trap.

The oolitic system of strata, as described by De Beaumont, Necker de Saussure, and Brochant de Villers, in the Tarentaise, Dauphiné, and the valleys near Mont Blanc, puts on a very different aspect from that which is usual in the more level regions of Germany, France, and England; and this difference appears similar to some occurrences mentioned by Studer and De Beaumont, which are obviously dependent on the heat of contiguous granitic rocks. In the Tarentaise, siliceous limestones, micaceous quartz rocks, and gypsum, correspond to the lias and lower oolitic rocks of England; and contain the fossils common in these rocks. It is further remarkable, that at the Col du Chardonnet (Hautes Alpes), plants, supposed to be of species which also occur in the coal formation, lie in beds which alternate with others containing belemnites of the lias. In the upper part of the Buet, Necker de Saussure has observed the following series of strata: viz., mica schist covered by various sandstones and schists; black slaty beds with talcose impressions of ferns; dark impure limestones; black slaty clay with nodules of Lydian stone, alternating with talcose slaty clay, both containing ammonites; and over all a grey calcareous belemnitic shale, to the top of the Buet.

Relative Antiquity of Pyrogenous Rocks.

The determination of the relative antiquity of the unstratified rocks is a point of much importance, and of great difficulty. Taken generally, it is an indeterminate problem; for though, in a vague sense, we may easily be satisfied that granitic and other felspathic rocks are more ancient than basaltic and other augitic rocks, yet there can be little doubt that some of these latter, as, for example, the bedded greenstones of Wales and Cumberland, are of higher antiquity than the granitic rock of Weinbohla, which rests on members of the cretaceous formation.

When we consider this question with reference to a small district, as, for example, the Island of Arran, so rich in various rocks of igneous origin, the result to be looked for is like that which may be gained by examining a volcanic mountain, where certain different rocks have at different times been ejected by the same volcanic forces. In Arran, for instance, we have granite, sienite, porphyries of many kinds, claystone, hornstone, pitchstone, greenstone, basalt. These cross and complicate one another; and it is possible, upon certain suppositions or admissions, to determine their relative antiquity. If the conclusion be substantially correct, and the order of production among these rocks be known, the interpretation may be trusted to the small extent of inferring, that below this small tract, at different successive times, rocks of different chemical composition existed in a melted state, and were forced upwards through rifts in the strata. The same thing is known with respect to modern volcanic accumulations, which change with time; and there remains for each case the same further question of the cause of these mineral changes under a given area of the earth's face.

The principle upon which the inquiry proceeds in the case of the older rocks, was strongly enforced and applied by Werner; but is not universally, though perhaps it is generally, admitted. Dykes fill fissures in stratified and unstratified rocks; mineral veins appear under the same circumstances. Where the rocks are distinctly stratified, and are of different qualities in the different beds, and contain organic remains in some or all of the beds, the proof that the fissures alluded to are of later date than the formation of the rocks is conclusive: therefore the dykes, which fill these fissures, are of still later date; and the same conclusion is extended to unstratified rocks: nor is it limited to the great masses of rocks. When dykes or veins intersect one another, that which is divided is the older, that which cuts through another is the newer. Thus, in the diagram (No. 92.), taken from Dr. Macculloch's drawing in the Geological Transactions, vol. iv. pl. 6. (S) the schist rock is divided by veins of granite (G),

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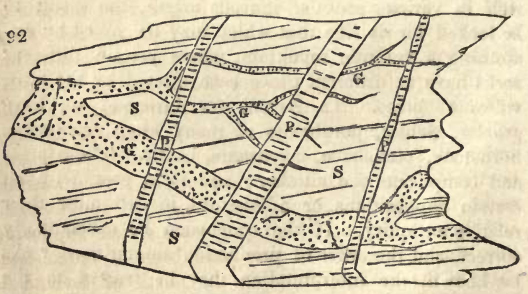


S. Schist. G. Granite veins. P. Porphyry dykes.

which fill ramified fissures, and are themselves crossed and cut through by straight dykes of porphyry (P). This occurs in Ben Cruachan, by the shore of Loch Awe.

Upon this principle Werner speaks confidently of the relative age of mineral veins; and it is the general impression of miners and geologists, that he is right in so doing.

On a greater scale, the same problem is presented to us by examinations of large districts, like Ireland, the Pyrenees, Cornwall, or the Bohemian mountains. But the data necessary for the solution of this problem are quite different, and the result becomes a part of the history of the formation of the crust of the globe. It is requisite to know in this case what relation the several rocks of igneous origin bear to the stratified rocks among which they appear. In this inquiry we must not assume that all the masses of igneous rocks of the same nature have been forced among the strata at the same time; this would be sometimes erroneous, always insecure. One of the most certain proofs of the exact age of a particular mass of igneous rock, is also one of the rarest. When strata *a, b, c, d* are traversed by a trap dyke, and these strata, together with the dyke, are overlaid by the next stratified rock in order of time *e,* it is evident that the dyke was formed in the interval (whether long or short) between the deposition of *d* and *e.* Such a case is believed to occur on the line of a trap dyke which crosses the Durham coalfield from Eggleston to Quarrington, dividing the coal strata, but not the superincumbent magnesian limestone. A similar dyke, starting from near the same point, passes into the oolitic system; and thus we learn that the igneous action in Teesdale, which commenced in the early carboniferous period, continued to produce similar basaltic rocks till after the deposition of part of the oolites; and there is nothing which prevents us from supposing that this last eruption may have been of much later date, as the great eruption in the north of Ireland is known to have been.

The great basaltic plateau in the counties of Antrim and Londonderry rests upon chalk; there are no tertiary strata above it: its date is therefore only known approximately: it was effused during the tertiary eras. The great basaltic masses of Mull and Skye, of Arran and Ayrshire, the Ochill Hills, &c., appear in directions and under circumstances which seem to connect them with the same seat of volcanic action as the Irish basalts; but data are wanted for determining the age of their eruption.

Mere association of igneous rocks with particular strata only proves that such rocks are at least not older than these strata: the case of the dyke traced by Mr. Murchison from the Breiddyn Hills (amid primary strata) and under and into the new red sandstone of Acton Reynolds, shows how very little propriety there is in classing trap rocks by the strata among which they have been injected; since this is, in fact, "a geological accident."

It is remarkable with regard to granite and rocks closely allied to it, that, excepting at a very few spots, among which Weinbohla on the Danube is the most remarkable, these igneous products are not seen in contact with any of the strata of the secondary or tertiary class. Granite touches gneiss at Strontian; mica schist in Ben Nevis; hornblende schist, argillaceous schist, and primary limestone in Glen Tilt; clay slate and grauwacke slate in Wicklow, Anglesea, Devon, and Cornwall.

It has been supposed that granites of different antiquity possess distinguishable mineral characters. The opinion is not improbable; but it is difficult to assure ourselves of its truth, because, as Humboldt confesses, it would be difficult to mention a granite which geognosts unanimously consider as anterior to every other rock. The same author observes, while speaking of "primitive" granite, "it appears to me that in both hemispheres, particularly in the New World, granite is most ancient when it is richer in quartz and less abundant in mica; and he notices the addition of horn blende as characterising the most modern granites. As before observed, the three granitic masses in the midst of the Cumbrian mountains present as many distinct sorts of granite, and each belongs to a distinct place in the series of slates. The Skiddaw granite is quartzose and micaceous, and underlies the lowest slate rocks; the Eskdale granite is quartzose with little or no mica, and lies among green slates of the middle division; the Shap granite contains but little quartz, is porphyritic in structure, and lies near the base of the upper Cumbrian series of slates. Whether these granites are of the same or very different geological eras, cannot be known without the most careful study of the district undertaken for the purpose.

Those geologists who think that the culmiferous strata of Devon form part of the carboniferous system of England, which overlies old red sandstone, may believe the granite of Dartmoor to have been erupted since the age of the mountain limestone; for the culm measures are greatly contorted where they approach the igneous rock.

At Weinbohla on the Danube, according to professor Weiss, confirmed by many subsequent authorities, occurs a real superposition of granite (or sienite) on chalk and green sand, which strata, usually horizontal, dip suddenly beneath the granite in some places, and rest upon it in others. (See De la Beche's Manual, for a detailed account.)

In the Pyrenees we learn from M. Dufrenoy, that granite sends veins into chalk, and converts it into granular crystallised limestone, and generates in it valuable veins of iron ore. This range of mountains is remarkable for showing contacts of granite with calcareous beds of the several eras of transition rocks, lias, and chalk, and in each of these cases the limestone become crystalline and metalliferous.

Our view of the history of igneous rocks will be both more complete and accurate by considering them in connection with the lines and points where the strata have been subjected to remarkable disturbance. By this means their true origin becomes, if possible, more clear, their relative antiquity less doubtful, their affinity to the products of modern volcanos more definite. As by the modern earthquake the ground is opened far beyond the reach of lava currents, so in earlier times great fractures were not every where filled with melted rock; but yet it is only along and near to lines of subterranean disturbance that the "hypogene" rocks have risen to the day. Their dependence on such dislocations is very unequal: granitic rocks show themselves in distinct connection with the principal ranges of mountains which mark the most considerable effects of modern subterranean disturbance. Minute scrutiny may show in many mountain chains that the granite, which is almost universally present, does not uniformly occupy the mineral or geographical axis or centre of the rocky group; — amidst the complicated displacements which there occur, this could seldom be exactly the case; but a glance at all good geological maps will satisfy the impartial student that the connection of granitic elevation, uplifted primary strata, and mountain country, is real, if not necessary, and of high theoretical importance. (See Vol. I. p. 38.)

Rocks which in some degree share with granite this character of central position, with respect to mountain ranges of primary strata, are hypersthenic syenite and common syenite, and certain porphyries which graduate into granite, and share its geological history. But the trap rocks generally, including in this term the augitic and hornblendic rocks, and the porphyries which are related to them, are differently circumstanced. Von Buch has remarked, concerning augitic porphyry, that it ranges parallel to, and is found constantly at the base of, great chains of mountains; and he attributes to this porphyry a powerful influence in the elevation of the mountains. If we consider the granites as supporting lines of principal movement among the stratified masses, and recollect that, on a great scale, the angle of elevation quickly diminishes as we proceed from the mountains, till, in plains not far remote, the strata retain their horizontality, we may say that the trap rocks are most abundant in points and in lines distributed between the granitic axis and the level plains. In some instances trap rocks occupy an extent of country not inferior to the area of granite. The Ochill Hills, the Campsie Hills the Pentland Hills, and others connected with them, form one great trappean country filling the vale of the Forth and Clyde, which is a great natural hollow between the ranges of the Grampians and the Lammermuir mountains, both elevated on axes of granite and syenite. Large breadths of trap rocks appear in Skye, Rum, Eigg, Mull, Arran, and Antrim; but in none of these cases is their appearance connected with ridges of stratified rocks, as granitic masses almost invariably are. Moreover these trap rocks, whether in the shape of dykes or overlying masses, are usually so disposed as to suggest the idea of volcanic action, determined to particular points, and bursting out and overflowing from particular lines, rather than a general expansion beneath immense areas of strata which seems best to agree with granitic elevations.

Trap dykes are frequently manifested along the lines of faults, and these may sometimes be determined in geological age by the circumstances which accompany the disturbed strata.

Keeping in mind these general facts, but disregarding the crude notions which attribute to granite or trap rocks the elevations and fractures which have merely opened to us their subterranean repository, or given them channels to the surface, we shall be able to construct a table of the relative antiquity of igneous rocks, by comparing their distribution with the principal phenomena of convulsion in the crust of the earth. Such a table, however, would be very incomplete if founded upon small geographical areas; as the imperfection of the following sketch, based on the examination of the British islands, will abundantly prove.

Table of the Principal Disturbances of the stratification of the British Islands, with the Igneous Rocks observed in connection therewith.

CLASS I.—BEFORE THE DEPOSITION OF OLD RED SANDSTONE.

Strata disturbed.	In what Manner.	Localities.	Igneous Rocks in connection.
a. Affecting Hypozoic strata chiefly.	Long ranges of gneiss, mica schist, chlorite schist, clay slate, primary limestone, &c.	The Grampian mountains generally. The primary mountains of Donegal.	Granite, sometimes syenitic, as in Ben Cruachan, Strontian, &c. Serpentine at Portsoy, &c., porphyry and greenstone not unfrequent.
b. Affecting Lower Silurians, &c.	Anticlinal axes of clay slate and grauwacke.	The Lammermuir mountains.	Syenitic granite, claystone, porphyry.
		The Cavan mountains.	Granite.
		The Wicklow and Wexford mountains.	Granite.
		Isle of Man.	Granite.
		Longmynd, near Shrewsbury.	Various traps.
		Snowdon range.	Greenstone, porphyry.
		Berwyn range.	Greenstone, porphyry.
c. Affecting all the Silurian strata.	Anticlinal axes of Cambrian and silurian rocks.	Cumberland and Westmoreland generally.	Granite of different kinds, porphyry, greenstone.

Note.—Most frequently it appears that the elevations of this class affect all the Lower Palæozoic strata which occur in the district. But in Wales there was a movement which preceded the Caradoc series, for example in the Longmynd, and there are other traces of *continued* movement in that region during the Lower Palæozoic period.

CLASS II.—BEFORE THE DEPOSITION OF THE LIAS.

Strata disturbed.	In what Manner.	Localities.	Igneous Rocks in connection.
a. Affecting the old red sandstone and carboniferous system generally, but not the magnesian limestone.	By anticlinals and synclinals, and great faults.	South Wales. Woolhope, Malvern Hills.	None.
		Abberford, in Yorkshire.	None.
		Quarrington, in Durham.	Basaltic dyke from Teesdale.
		Manchester.	
		Somersetshire coalfields.	?
		South Wales. Caradoc and Wrekin.	Felspathic, epidotic, and greenstone trap.
b. Affecting the magnesian limestone, or its equivalent.	By great faults.	The Penine fault. (Vol. I. p. 194.)	Granitic porphyry. (Dufton Pike.)
		The 90 fathom dyke. (Vol. I. p. 194.)	None.
		The Craven fault. (Vol. I. p. 194.)	Red felspathic dyke.
		In the Coalbrookdale coalfield.	?
		South Wales.	
c. Affecting beds of the new red sandstone formation.	Fault or small anticlinal.	Acton Reynolds, Shropshire.	Dyke of greenstone from the Breiddyn Hills.
		Island of Arran.	Dykes of porphyry, claystone, hornstone, pitchstone, basalt, greenstone, &c.
	Great uplifting.	Arran.	Granite of Goatfield, &c.

Class III. — Before the Deposition of the Lower Green Sand.

Strata disturbed.	In what Manner.	Localities.	Igneous Rocks in connection.
Affecting the oolitic rocks generally, but not any part of the cretaceous system.	A broad axis of elevation.	Yorkshire (Bishop Wilton).	None.
	Unconformity of dips.	Bowood. Blackdown.	None. None.
	Great dyke and fault.	Yorkshire. (Moors near Whitby). (Vol. I. p. 231.)	Basaltic dyke from Teesdale.
	Complicated effects.	Skye, Eigg.	Sienite, hypersthenic and other trap rocks, pitchstone of Eigg.
		Ord of Caithness. (Vol. I. p. 231.)	Granite.

Of doubtful age. — The gentle anticlinal of coralline oolite near Bottisham (Cambridgeshire), which perhaps affects the lower greensand of Ely. No igneous rocks. Professor Sedgwick discovered it.

Class IV. — Since the Deposition of the Chalk.

Strata disturbed.	In what Manner.	Localities.	Igneous Rocks in connection.
Affecting, perhaps, all the tertiary strata which occur in the district.	Anticlinal axes. (See Vol. I. p. 276.)	Weald of Kent and Sussex. Isle of Wight.	None. None.

CHAP. VIII.

MINERAL VEINS.

Werner, in his valuable treatise on veins, distinguishes between "true veins" and some other appearances which he thinks undeserving of the title. "Veins" he declares to be particular mineral repositories, of a flat or a tabular shape, which in general traverse the strata of mountains, and are filled with mineral matter differing more or less from the nature of the rocks in which they occur. They cross the strata, and have a direction different from theirs; they are rents which have been formed in mountains, and have been afterwards filled up by mineral matter.

In this definition rock dykes are included, and it sometimes happens that those dykes are metalliferous; but the substances associated with tin, copper, lead, and the other minerals for which veins are valued, are usually quite different from the matter of rock dykes. Felspar and augite, so common in trap rocks, are almost unknown in metalliferous veins, which contain, in fact, few silicates of any kind, though quartz (of a peculiar aspect) is very frequent therein. Besides the metals, in combination with sulphur, carbonic acid, &c., salts of lime and barytes abound, and clays of different qualities appear.

Thus the distinction between rock veins and rock dykes is in their contents; and since we find both in the same districts, in similar fissures, and under similar circumstances, this difference is of such importance, that, however strong may be the arguments which tend to show that mineral veins are the result of igneous action among the masses of the globe, we cannot fail to perceive that this action was materially different in the two cases.

Geographical Distribution.

On no part of the history of veins has observation pronounced a more positive decision, than on the relation borne by their distribution to physical geography. The truth is universally recognised, that while extensive plain countries are utterly deprived of all indications of these valuable mineral deposits, and others contain them but rarely and in small quantity, there are few mountain countries in which mineral veins are not found in abundance and variety. They are, indeed, not equally nor uniformly distributed even in their more favoured regions: their occurrence is sufficiently dependent on other causes, besides the mere form of the surface, to keep alive the curiosity and inflame the enterprise of the miner, as well as to conduct the philosopher one step further in his research into the mysterious structure of the earth. Taking a general view of the mining districts (not herein counting the collieries) of Great Britain, we see the Grampians, and Lammermuir, and Cumbrian mountains; the great ridges of Northumberland, Durham, Yorkshire, and Derbyshire; the anticlinal axes of the Isle of Man, Anglesea, Snowdonia, and Shropshire; the elevated boundaries of the coal tracts of Wales, and Somerset; the mountain chain of Devon and Cornwall; the elevated ranges of Wicklow, and Wexford, of Leitrim, Sligo, Mayo, and Galway; all rich in lead, copper, zinc, tin, &c., with some silver, and traces of gold. On the other hand, the broad valleys of the Forth, Clyde, and Tweed; the wide vales which surround the Cumbrian, Yorkshire, Welsh, and Devonian mountains, contain almost no mines; and the central plains of Ireland hardly yield any metallic treasures. The same contrast appears on the continent of Europe, between the mountainous and metalliferous tracts of Brittany, the Pyrenees, the Harz, Erzgebirge, Oural, &c., and the great Plains of France, Germany, and Russia.

In considering further the situations of mineral veins, we are struck by another feature of their geographical distribution. There are some general directions, common not to all, but yet to a very great majority of the veins of the British islands. More than half of the *productive* veins pass in east and west lines, or rather a little N. of East, and S. of West, in the mining districts of Cumberland, Yorkshire, Derbyshire, North Wales, Shropshire, and Cornwall. The same directions prevail in Brittany, the Harz, Hungary, and, according to Mr. J. Taylor, in Mexico. Hence, veins running east and west are commonly called *"right running" veins*, while others, which in the same districts are generally *unproductive*, and run very often north and south, across the productive veins, are often called *"cross" veins*. (For proofs of these truths, Werner on Veins, Williams's Mineral Kingdom, Forster and Sopwith's Accounts of Aldstone Moor, and Farey's Derbyshire; Mr. Carne, in the Geol. Trans. of Cornwall; Mr. J. Taylor on Veins, in the Brit. Assoc. Reports, may be consulted.) Now as the directions of the mountain masses to which these veins are geographically related are various; the greater number ranging N. E. and S. W.; some (Yorkshire, Derbyshire, Flintshire) north and south; others, Pyrenees, Harz, Carpathians, E. S. E.; it is requisite to take other circumstances into account, before deciding to what extent these prevalent directions of the mineral veins are dependent on the direction of the mountains which they enrich.

One of the most obvious and interesting points of inquiry is the dependence of the occurrence of metalliferous veins on the *age* of the rocks; and Werner, as might be expected from the tenor of his generalisations, ventured boldly to pronounce concerning many metals, the order of their antiquity in the crust of the earth. Judging from the rocks in which they frequently occur, tin, molybdena, tungsten, and wolfram are ranked as the most ancient metals; uranium and bismuth stand next, "having been found in veins in transition or secondary strata." Gold and silver are considered comparatively new; copper, lead, and zinc occur in deposits of various ages; arsenical pyrites ranks as an old product, cobalt as new, magnesia is of intermediate, and iron ores are of all ages.

Though these doctrines of the relative antiquity of the metals must now be greatly modified, the subject of the distribution of metallic ores according to the place of the rocks in the scale of stratification, is still one of the most curious in geology, and valuable in mining. It is certain that such a dependence exists, and probable that the accurate knowledge of it would be important in clearing up some great difficulties in the theory of mining. The variety of metallic and earthy minerals in the veins which traverse primary slates in Cornwall, Cumberland, and the Lead Hills, is very great and remarkable when compared to the small catalogue of these found in the secondary limestones of Flintshire, Derbyshire, and Durham. While argentiferous lead ore, and salts of lead, copper ore, blende, calamine, pyrites, carbonate of iron, quartz, carbonate of lime, sulphate of barytes, fluor spar, &c., are common to these and the Cornish districts, the latter yield ores of silver, tin, bismuth, cobalt, arsenic, antimony, uranium, &c., opal, jasper, garnet, zoolites, tourmaline, schorl, epidote, asbestus, steatite, &c.

There is a remarkable circumstance in the distribution of metallic veins in the same class of stratified rocks, — a peculiarity depending on local influences; such, that while the slates of Cornwall near the granitic eruptions, yield tin and copper, and the Snowdonian slates, and those of Coniston Water Head yield copper; those of Loweswater, Borrowdale, Patterdale, and Caldbeck fells yield lead, or lead and copper. Copper ore and red oxide of iron occur in the limestone of Furness; lead ore and calamine in that of

Derbyshire, Flintshire, and Mendip. In the same manner the veinstones vary; even the calcareous spar is crystallised with quite different planes in the mines of Aldstone and Derbyshire.

The limits of mining districts are often very decided. In the rich mining tract round Cross fell, dissected like a map by mineral veins, and worked with an enterprise worthy of all praise, no instance (we believe) has yet occurred of a single vein being traced to the western side of the mountain range, *across the great Penine* fault, so as to penetrate the slaty rocks that rise in the line of dislocation. The same fact is witnessed again, in almost precisely similar circumstances, in the Flintshire veins, which do not, *in a single instance,* enter the subjacent silurian rocks of the Moel Fammau range, which rises on the line of a great axis of movement. Numerous instances of this remarkable dependence of the occurrence of mineral veins, in limited portions of country definitely related to particular lines of disturbed strata, are well and familiarly known.

Occurrence of Mineral Veins near Centres of Igneous Action.

Ever since the analogy of mineral veins and rock dykes has been clearly perceived, and the dependence of these latter on disturbance of subterranean temperature recognised, the dependence of the occurrence of mineral veins on the general influence of heat has been continually more and more apparent. This appears to have been strongly felt by Boué and Humboldt; there are also passages in the writings of Von Buch which conduct to the same conclusion. M. Necker presented to the Geological Society, in 1832, an attempt to bring under general geological laws the relative position of metalliferous deposits with regard to the rock formations of which the crust of the earth is constructed. The doctrine of the sublimation of the metalliferous contents of veins from igneous matter occurred to the author, twelve years previously, from observing the deposition of specular iron on the crust of a stream of lava flowing down the side of Vesuvius; and he was induced, from that circumstance, to institute an investigation of the subject with reference to the following questions: —

First, Is there, near each of the known metalliferous deposits, any unstratified rock?

Secondly, If none is to be found in the immediate vicinity of such deposits, is there no evidence, derived from the geological constitution of the district, which would lead to the belief that an unstratified rock may extend under the metalliferous district, and at no great distance from the surface of the country?

Thirdly, Do there exist metalliferous deposits entirely disconnected from unstratified rocks?

With respect to the first of these questions, the author showed, by copious references to England, Scotland, Ireland, Norway, France, Germany, Hungary, the Southern Alps, Russia, and the northern shores of the Black Sea, that the great mining districts of all these countries are immediately connected with unstratified rocks: and in further support of this solution of the first question, he mentions the metalliferous porphyries of Mexico, and the auriferous granite of the Orinoco; but he observes, that his knowledge of the mining countries of South America is not sufficient to enable him to state their general geological connection. Locally, this truth is well known. Mr. R. Fox, in his excellent summary of facts regarding the veins of Cornwall, observes:—"The copper and tin mines are generally situated at or near some of the junctions of the granite and killas, or of killas and elvan," &c.: and both of these metals have been found in great abundance in each of these rocks; and it is, perhaps, difficult to decide in which of them either metal has, upon the whole, predominated.

With reference to the second question, — the probable association of metallic veins with unstratified rocks, though the latter are not visible in the immediate neighbourhood of the former,—the author gives a section of the country between Valorsine and Servoz, and points out the probable extension of the granite of Valorsine under the Aiguelles Rouges and Mont Breven, composed of protogine, chlorite, and talcose schists, to the immediate vicinity of the mines of Servoz, which are situated in the latter formation. He also refers the reader for further illustration to the metallic deposits of Wanlockhead and the Lead Hills; to the mines of Huelgoet and Poullauen in Brittany; to those of Macagnaga and Allayna at the foot of Mount Rosa; to those of Sardinia, Corsica, and Elba; to the metalliferous veins of the Vosges, Brescina in the Alps, and the Altai chain; all of which occur in districts where unstratified rocks are known to exist.

In reply to the third question, — Do their exist metalliferous deposits entirely disconnected from unstratified rocks? — the author enumerates the mines of the Netherlands, those of quicksilver at Idria, the lead mines of Poggau in the valley of the Mur; Pezay and Macoz in the Tarentaise, and the veins of galena in the mountain limestone of the south-west of England. (See Geological Proceedings, 1832.)

On considering the cases mentioned by Mr. Necker, of metalliferous veins entirely unconnected with great masses of unstratified rocks, we perceive they are not unaccompanied by great dislocations of the strata, such as are usually associated with the appearance of trap rocks at the surface. It is probably not to the "Whin Sill" that the rich and abundant lead mines of the whole district extending from the Tyne to the Aire are due, —for indeed, through all the southern portion of this tract, almost no igneous rock appears,—but to the mighty and continuous disruption of strata caused by disturbance of interior heat, which bounds the mining district. In like manner, the very rich mining tract of Flintshire is unconnected with igneous rocks, but is defined, and is obviously dependent on the great disruption of strata along the eastern side of the vale of Clwydd. The

Mendip hills offer a similar example of veins which depend on an axis of movement, though no igneous rocks appear on the line.

Again, in several smaller instances, the relation of lead and copper veins to axes of dislocation is obvious; witness the lead veins which *cross* the anticlinals of Greenhow Hill, Bolton Bridge, Bolland, &c. (see Illustrations of the Geology of Yorkshire), in none of which situations is there the smallest indication of igneous rocks near the surface.

Now, as in all these cases the subterranean movement has opened a passage to the interior regions of the earth, we see that M. Necker's propositions are not negatived, provided we suppose these communications to have been traversed by the sublimations to which he ascribes the origin of the substances in veins. Whether the particular mode of igneous action (sublimation from heated rocks), proposed by Mr. Necker for investigation, be the true method of nature or not, it is clear that his researches, followed out, justify a confident belief that proximity to, or communication with, masses of igneous rock, is a condition remarkably and generally influential on the production of metalliferous veins in the stratified rocks.

Taking, then, the element of heat as of great importance in explaining the leading facts connected with mineral veins, we are prepared at once with answers to the obvious question, Why are the metalliferous veins, beyond all comparison, most plentiful in primary and early secondary (transition rocks of Buckland) strata? — Because these rocks, as being nearer to the ignigenous masses below, must have experienced, more than those of later origin, the general influence of heat. We are also enabled to account for the exceptions to this rule in the Pyrenees, where, according to M. Dufrenoy's interesting examination (*Mémoires sur les Mines de Fer des Pyrenées*, 1834), ores of iron accompany the ramifications of granite even in the cretaceous formation. There are, in fact, in the Pyrenees, three repositories of iron ores.

1. At the separation of transition strata and granite in the slopes of the Canigou.
2. In limestone of the lias epoch, at Rancié.
3. In the cretaceous formation, accompanying granitic ramifications, at St. Martin in the valley of Gly.

All these deposits of iron ore are found where the rocks touch or approach very near to the granite ; and from all the circumstances, M. Dufrenoy is apparently well justified in viewing the occurrence of the ores as dependent on the proximity of granite, and independent of the antiquity or other characteristic differences of the rocks in which they lie.

Lest this result should lead us too far, and confound all the variety of phenomena connected with mineral veins in the vague and valueless notion of "the effects of heat," it appears right to point the reader's attention to such localities as the Island of Arran, where the proximity of the granite is marked by abundance of rock dykes, but shows almost no trace of mineral veins. The dependence of metallic veins upon local centres of igneous action, is certainly very different from that of rock dykes, as might be safely inferred from many essential differences between them in countries where they occur together.

Relation of Veins to the Substance and Structure of the neighbouring Rocks.

Before proceeding to trace the relations which really exist between the substance of the veins and the neighbouring rocks, a more minute description of the forms and contents of veins must be attempted than was necessary for the preceding inquiries.

The *fissures* now occupied by veins pass through all the rocks met with in their downward descent. Though a few instances are supposed to be known of their termination, at some considerable depth, all large veins continue beyond the reach of the deepest mine. Their horizontal extent is various: some veins run 5, 10, or more miles through a country; and, in fact, their termination is not really known, except that they are lost in mere cracks not worth the miner's attention. But so variable is the breadth of veins, that extreme contractions and considerable expansions sometimes confuse all regularity, and render doubtful even the connection of the seemingly disunited parts of such veins. "If we take a vein of 3 or 4 feet to represent a fair average size, it may be only an inch or two wide in one place and 8 or 10 feet in another. Such extremes not unfrequently occur within a few fathoms of each other." * Other veins preserve an almost unvarying breadth and freedom from these perplexing contractions; and we believe these differences of character may be distinctly referred to the natural structure of the rocks, and the movements to which they have been subjected.

Veins, in their descent through the rocks, approach more or less to a vertical position; their deviation from it seldom exceeds 10 degrees in the mining countries of the north of England; but in Cornwall, so rich in complicated phenomena, the underlie, or deviation from the vertical, is supposed by Mr. Fox to average 20 degrees, but seldom to exceed 45. The mechanical theory of these inclinations of veins is yet altogether imperfect; we do not know in what degree these peculiarities depend on original jointed structure of the rocks, nor how to refer their various directions to sudden fractures or gradual pressures, such as Werner pictured to himself. Nor shall we escape from this ignorance, until the directions taken by the veins, or, to speak more accurately, the planes of their fissures, are compared geometrically with the planes of the joints, the planes of stratification, and the local axes of elevation and depression. In the lead mining districts of the North of

* Fox, in the Report of the Polytechnic Society.

England, a notion exists that the greater number of veins are at right angles to the planes of stratification: this idea is put as a general assertion by Williams (*Mineral Kingdom*, vol. i. p. 317.), a writer whose extensive experience in mining renders even a dogma of this nature worth recording. His words are, "rake veins have a greater or lesser hade or slope in proportion to the declivity of the strata, as the mineral fissure, or vein, is a transverse section cut at right angles to the lay or bed of the strata;" —"whatever be the slope of the strata one way, the hade or slope of the vein is as much from the perpendicular the other way." And he then confines this remark to veins which range with the bearing of the strata; distinguishing them from others which "cut right across the strata," and a third group cutting them diagonally, which he rightly terms "oblique veins." The reader who compares this description of the ordinary relation of the deviations and dip of veins, with Mr. Murchison's notices of the prevalent character of the joint planes in the silurian rocks, will not fail to perceive the conformity of two independent sets of observations, and gather in consequence a useful notion of the affinity of vein fissures, and the divisional planes which constitute a part of the structure of all stratified rocks. It is much to be wished that the triple co-ordination recommended above, as necessary to a just view of the origin of vein fissures, should be carefully executed on many of the complicated phenomena of the Cornish mines. The cleavage planes of the slaty rocks, which inclose mineral veins, should also be included in the survey.

Some veins, like rock dykes, occupy one "clean" fissure of the rocks; others branch off into strings, or become divided into forks, which continue for a longer or shorter space till they are lost in clefts of the rocks, or turn to re-unite themselves with the main trunk. Such "strings," or "feeders," as they are called in Cornwall, appear under very various circumstances, both on the horizontal and vertical sections. Occasionally a poor vein is worth following for its rich lateral strings; and it is a common notion of miners that such appendages are influential on the productiveness of a vein.

One of the most curious accidents which affect a vein fissure, is its bending or expanding against particular layers of rock, so as to constitute what, in the mining country of Aldstone Moor, are called "flats," or lateral extensions parallel to the stratification. These are often cavernous in the middle, and yield beautiful crystallisations.

Veins sometimes appear as one united mass, due to one single or uninterrupted deposition of mineral substances; in other cases there are divisions in the veins, or by the side of them, which contain clay or quartz ribs, or in some other way give indications of successive rents in the same general direction. Such appearances have been often noticed (as by Werner, Carne, Fox, &c.), and considered as capable of explaining, in some instances, the curious and very common accident of portions of the neighbouring rocks, enveloped in the mass of the veins, always near to and even opposite to the parts whence they were disjoined. Such portions of the neighbouring rocks are called "*rider*," and being frequently traversed and impregnated by the vein substances, acquire a characteristic aspect; which being found again not unfrequently in the rock on the sides of the vein, especially where "strings" pass off from the mass of the vein, such bounding rocks are said to be "*ridered*."

In this manner, by (successive?) nearly parallel rifts in the rocks, which all received mineral depositions, a "strong vein" becomes of almost indefinite width, even 30, 40, or more feet across, and often bewilders the miner, unable to interpret or follow the seemingly capricious manner of the mineral aggregation.

The rocky boundaries of the veins are often somewhat peculiar in character near the vein: sometimes, as in the case of rock dykes, they appear harder than the rest of the rock; at other times some difference of mineral impregnation, pyritous, or serpentinous admixture, appears, which distinguishes the so-called "*walls*" of a vein. But this term is apt to mislead a geologist into the notion that some definite parallel band always insulates the vein from the inclosing rock; which is, in general, not the fact. In Cornwall generally, it is thought by Mr. Fox that the rocks diminish in hardness near a vein; and similar facts are mentioned by Werner.

A curious circumstance is noticed by Mr. Fox and others, regarding the arrangement of the quartz in the cross courses of Cornwall. This mineral does not in such cases appear in its usual pyramidal or prismatic crystallisation, but is of a fibrous structure, the axes of the fibres lying across the vein, exactly as we may see in hundreds of examples in thin quartz veins which divide argillaceous slate, and other rocks. There are in some cases several parallel plates of this fibrous quartz, marking successive small rents.

In the cross courses of Cornwall, which contain quartz, clay, and other substances, these are very commonly arranged in alternate layers parallel to the walls. (Mr. Fox.) The same thing obtains very generally, though not universally, in veins of all ages and contents; as the small specimens commonly sold in Derbyshire very prettily illustrate. It is generally to be observed in such cases, that the crystallisations are so arranged that the terminal faces point inwards each way from the walls of the vein, and that those bands of crystallisation which are nearest to the walls, have themselves served as surfaces of attachment for the next layer, which is usually moulded on the other as if that had been deposited first. This appearance has suggested successive irruptions of melted matter, successive secretions from solution, successive accumulations from sublimation, and successive depositions by electrical currents, to persons whose views led them thus diversely; but a *succession of operations* is commonly (not universally) admitted to explain these appearances.

Another peculiar appearance in mineral veins, noticed by Williams, Fox, Henwood, and others — and which from personal inspection the author knows to be frequent both in primary and secondary mining tracts — is the segregation of the metallic contents of a vein into portions inclined at various angles in different veins, but nearly parallel in the same vein. These are called "*pipes*" or "*shoots;*" and their occurrence is of such importance, as to mark, in a long vein, a series of parallel spaces more than usually metalliferous. The relation of these pipes of ore to the natural structures of the neighbouring rocks is a subject of research strongly to be recommended to intelligent mine agents, both for its practical and scientific value. Mr. Fox observes, from the information of Mr. R. Tregaskis, that when veins are nearly at right angles to the beds of killas, the masses of ore which they contain are generally conformable, in their underlie, to the direction or dip of such beds; in other words, they usually take an oblique direction in the veins, and form what the miners call "*shoots*" of ore: and when the directions of the beds and veins are nearly parallel to each other, the ore has not usually any independent dip or shoot in a lode; it is then termed a "*pipe*" of ore.

According to Mr. Henwood (*Mining Review*), the "shoots" usually dip *from the granite, and towards the slate,* whichever of them may be the containing rock.

The reality of the dependence of the distribution of metallic ores, in a continuous vein, upon some qualities of the surrounding rocks, is very perfectly demonstrated by facts known in the north of England. The mining districts of Aldstone Moor, Teesdale, Swaledale, &c. consist of shales, grits, and limestones, traversed by east and west and north and south veins, which variously dislocate the strata. In the course of these unequal dislocations, coupled with unequal thicknesses of the strata, various *oppositions* of the argillaceous, arenaceous, and calcareous rocks happen; and there are simple rules which seldom fail in determining what parts of a vein may be found productive. First, it is chiefly in the limestone district that the veins are productive, though the fissures traverse a vast thickness of superincumbent shales, grits, and coal. Secondly, in a series of limestones, gritstones, and shales, which margin a vein, it will happen that, when inclosed between walls or cheeks which are both argillaceous, the vein will be unproductive, and generally " nipped," or reduced in width; with argillaceous beds on one side, and gritstones or limestones on the other, the same effects appear, but in an inferior degree; gritstone opposing gritstone yields irregular results, according to the mass and quality of the gritstone, so that in several districts (Grassington, Allenhead, &c.) much lead ore has been found in such situations; but when limestone is opposite to limestone, the vein is always most productive. Now, if we consider that, in the many displacements of veins, a thick limestone rock will be less frequently carried altogether away from its fellow beds than a thinner one, we see at once a reason why the " main limestone" of Swaledale (or " twelve fathom" limestone of Aldstone) is by far the most productive among the "bearing beds" of those counties; for *it is the thickest limestone* there known. There may be other reasons in addition; but this is obvious and important, and agrees with an opinion of those countries, which affirms that veins of small amount of dislocation (or " throw" as it is called) are, on the whole, more regularly productive than those attended by enormous displacement. (See Forster and Sopwith on the Veins of Aldstone Moor; and Geology of Yorkshire, vol. ii.)

In Cornwall, some veins bear tin or copper both in granite and killas; others yield more in one of these rocks; the veins are also very unequal in their produce in relation to depth from the surface; yet, as a general result, it seems to be admitted by all writers, that the contents of the veins undergo real and decided variations wherever the bounding rocks (or "country," as the miners term the mass of rocks adjoining a vein) experience changes of their nature or structure. (See the papers of Mr. Carne, Fox, &c. in Trans. of Geol. Soc. of Cornwall; Mr. Taylor's Report; Henwood's Survey, &c.)

The same truth of the dependence of the contents of mineral veins upon the containing rocks is put in a strong light by Von Dechen, in his translation of De la Beche's Geological Manual. He notices the mechanical dependence of the *width* of the vein upon the solidity of the neighbouring strata, and points out other phenomena analogous to what have been mentioned above. "The veins of Kupferberg, in Silesia, bear ore only in hornblende schist, and become impoverished in mica schist." "At Stadtberg, veins which divide zechstein, kupferschiefer, and the subjacent clay slate and flinty slate, never bear ore above the kupferschiefer." At Bieber, cobalt veins traverse the kupferschiefer, and are unproductive in the subjacent red mica schist."

It has been generally thought that depth below the surface of the earth was influential on the quantity and quality of ore contained in a vein. Pryce, writing in 1778, says,—"The richest strata for copper is between 40 and 80 fathoms deep; and for tin between 20 and 60; and though a great quantity may be raised of either at fourscore or 100 fathoms, yet the quality is often decayed, or *dry of metal*." * This does not appear confirmed by recent experience, which has in some instances (Dolcoath mine) gone to the depth of 260 fathoms without exhausting the supply. That copper, upon the whole, occupies greater depths than tin, is a common opinion in Cornwall. Mr. W. Phillips observes, "At about 80 or 100 feet under the surface, the first traces of copper or tin are usually found; rarely nearer to it than 80 feet. If tin be first discovered even without a trace of copper, it is not unusual that, in the course of sinking 80 or 100 feet or more, *all trace of it is lost*, and copper only is found; but if, instead of tin, copper be first discovered at a

* Mineralogia Cornubiensis, p. 79.

depth of 80 or 100 feet, it seldom or never happens that tin is found below it in the same vein." Mr. Fox adds,—"There are, however, many instances of tin ore accompanying copper ore to a great depth; and in Dolcoath mine it is found in a copper lode more than 200 fathoms below the surface, and even under the copper." Mr. Carne observes,—"In general an ochreous oxide of iron (gossan) is found in the upper part of the copper veins, to which sulphuret of iron ('mundic') frequently succeeds, below which the miners confidently expect to obtain copper ore."

Relation of Veins to each other.

Adopting the opinion of Werner, that veins which cross and cut through others are of newer formation, we shall find great interest in the description given by Mr. Carne of the principal vein systems of Cornwall *, and Werner's earlier classification of the veins of Freyberg.

Mr. Carne, distinguishing between contemporaneous veins and those which he considers as "true veins †," arranges the latter according to the difference of their antiquity, as inferred from their observed intersections, in eight classes.

The *First Class* includes *the oldest tin veins.* The underlie of these oldest tin veins is to the north; they are traversed by those of the second class. They form a very large majority of the whole.

The *Second Class* includes *the more recent tin lodes.* There are few veins of this class; they underlie to the south. The tin veins are generally east and west veins ‡, ranging from 5° to 15° south of east and north of west; in some cases due east and west; and less frequently north of east and south of west. In St. Just,

* In the Trans. of the Geol. Soc. of Cornwall, vol. ii.
† In Cornwall, metalliferous veins are called "lodes."
‡ The directions are by compass, whose westerly variation is in Cornwall about 25°.

nearly S.E. and N.W. In Polgorth one is north and south.

The veinstones of tin lodes are quartz, chlorite, capel (quartz and schorl, or quartz and mica, or quartz, schorl, and chlorite), and rarely schorl, or fluor. The width of tin lodes varies from 36 feet to a mere string; the average being from 1 to 4 feet. The average underlie is about 2 feet in a fathom: extreme cases give 10 feet; or, in contact with copper lodes, 16 feet. Most of the productive tin lodes have been found in a slaty country.

To the *Third Class* belong the *oldest east and west copper lodes*. These form the great majority of the copper lodes of Cornwall. Their veinstone is generally quartz; sometimes fluor, quartz and fluor, capel, chlorite, hornstone and porphyry, or calcedony. The average width is not more than 3 feet.

The direction is mostly south of east, and north of west, about 10° upon an average; sometimes E. and W.; or north of east and south of west. The underlie is various, but generally northwards; in a particular tract mostly southwards; in some cases the same vein changes its underlie from north to south. The average amount of underlie is 2 feet per fathom, the greatest 8. These copper lodes always traverse tin lodes. They are usually accompanied by small veins or partings of clay, called by miners "flukan."

The *Fourth Class* is composed of the *contra* copper lodes*. These are similar to the third class, excepting in their direction, their greater width, and their having more flukan in their composition. The average width may be stated at 4 feet.

Their direction is in general from 30 to 45 degrees south of east and north of west; some, however, run in an opposite direction, namely, north-east and south-west.

Their underlie is much the same as that of the other copper lodes, to which they are much inferior in number.

* Veins which range from 30 to 60 degrees north or south of the east and west points are called CONTRAS.

The *Fifth Class* includes the "*cross courses:*" these are sometimes composed wholly of quartz, but they usually contain, besides quartz, a large portion of flukan, and sometimes of gossan.

Their width is usually greater than that of the veins previously mentioned, averaging at least 6 feet.

Their direction is usually west of north and east of south, but sometimes north and south, or east of north and west of south.

Their underlie is various: most of those which point east of north, underlie towards the west; and on the contrary, those which point west of north, underlie towards the east.

Cross courses have been traced for several miles: they rarely yield tin or copper; lead is the principal metal found in them.

In the *Sixth Class*, the *more recent copper lodes*, which are not numerous, nor in their size, direction, or underlie, materially different from older veins of this metal which have been described. They have more clay in them than is usually seen in the cross courses.

The *Seventh Class* contains the *cross flukans*, or cross courses which are composed wholly of clay; they are seldom more than one foot wide, but no water passes through them.

Their general direction is nearly north and south: their underlie is much the same as that of the cross courses, generally towards the east.

In the *Eighth Class* are ranked the *slides*, which are composed wholly of slimy clay, and appear like natural partings in the rock.

They run in all directions, but in general are nearly parallel to the tin and copper lodes, which they throw up or down. They are narrow, and underlie very fast.

It has been observed by Mr. Carne, as a result of the preceding investigations, that "veins which contain the greatest quantity of flukan or clay, are generally found to traverse those which contain a less quantity or none at all of that substance;" and this generalisation is confirmed by several facts communicated to Mr. Fox by the intelligent mine agents of Cornwall.

Werner used the same method of classification as that employed by Mr. Carne, for the phenomena which attend the mineral veins in a district as rich in metallic treasures as Cornwall; and the examination is the more valuable in comparison, because the treasures are generally different, and lie in different strata. Gneiss is the great repository of metallic veins in the Freyberg district, and argentiferous lead ore the principal product. The ancient mining district in question is only about two German miles long, and one broad; yet, within these limits, Werner observed at least eight principal deposits of metallic veins, perfectly distinct from one another, and for the most part containing different metals. Of the veins which are thus distinguished, the first four intersect one another, so as to give a definite scale of antiquity, but the last four are obscurely characterised in this respect from other considerations.

The first, and decidedly the most ancient, of these deposits, which yields argentiferous lead glance (galena), is one of the most important of the whole district, having constantly yielded, since the earliest period of working the mines of Freyberg, a large quantity of lead and silver, and a smaller of copper. It consists of coarse granular lead ore, with silver in the proportion of $1\frac{1}{2}$ to $2\frac{1}{2}$ oz. in the quintal; common arsenical pyrites; black blende in large grains; common iron and liver pyrites; a little copper pyrites; a little sparry ironstone. The veinstones are quartz; and sometimes a little brown spar, and calc spar. The various substances here named are not believed by Werner to be all of the same antiquity, but to have been formed successively in the vein, the oldest being nearest the sides.

These veins are from $2\frac{1}{2}$ to 6 feet across, and are chiefly *northern veins.*

The second metalliferous deposit yields lead mixed with a larger proportion of silver than any other. It contains lead glance, very rich in silver; black blende, small granular; common iron and liver pyrites; a little arsenical pyrites. Dark red silver ore, brittle silver ore, white silver glance, and plumose antimony ore also occur. The veinstones are principally quartz, much brown spar, and calc spar. There is a difference of situation in the vein, characteristic of these substances; quartz is generally on the outside. The veins are from 2 feet to 10 inches wide, and are *south* and *south-west veins.*

The third deposit yields lead glance, with but little silver. Its contents are lead glance, with nearly an ounce of silver to the quintal; much iron pyrites; some black blende; a little red iron ochre. The veinstones are quartz; sometimes also chlorite, mixed and surrounded with clay. These are all *northern veins.*

The fourth deposit is also composed of lead glance, with but little silver (from a quarter to three quarters of an ounce of silver to the quintal). Besides the lead ore, there is radiated pyrites, and sometimes a small quantity of brown blende. The veinstones are very distinct, and consist of heavy spar, fluor spar, a little quartz, and rarely calcareous spar. The veins are from 1 foot to a fathom in width, and have generally a *western direction.*

(To this vein system, Werner refers many deposits beyond the Saxon districts, not hesitating to include the Derbyshire mines, which certainly offer several interesting analogies as to the veinstones, the direction, and contents of the veins.)

The fifth deposit contains native silver, silver glance, and glance cobalt, besides a small portion of grey copper ore; lead glance rich in silver; a little brown blende; and sparry ironstone. The veinstones are disintegrated heavy spar, and blue fluor. It always occurs *at the intersection* of the *southern* and *western* veins (or first and fourth vein systems here described), or in *the middle of the western veins.*

The sixth deposit consists of native arsenic and red silver ore, with sometimes a little orpiment; and rarely a little copper nickel, glance cobalt, native silver, lead glance, iron pyrites, and sparry ironstone. The veinstones are heavy spar, green fluor, calcareous spar, and a little brown spar. Occurs in the *intersections* or in the *middle of veins.*

(The distinction of age between this and the last system is obscure.)

The seventh deposit consists of red ironstone, containing also a little iron glance, quartz, and heavy spar. Occurs *in the upper parts* of veins.

The eighth deposit contains copper pyrites, mountain green, malachite, red and brown iron ochre; with veinstones of quartz and fluor. It is of small importance.

In the valuable lead mines of Aldstone Moor, cases of intersection so complicated as those of Cornwall and other tracts of primary strata seldom or never occur. The main facts are the general east and west direction (by compass) of the lead veins, and the intersection of these by cross courses which range, like these in Cornwall, mostly west of north and south of east. Their "throw" is sometimes very great. The underlie of the veins is seldom considerable; and being mostly in the same direction in each mining field, intersections of the veins are not commonly met with. The cross courses are, as in Cornwall, commonly wider than the veins, and seldom produce any thing valuable. The veinstones are quartz, fluor, carbonate of lime, sulphate of barytes, &c.

That veins are enriched near the places where they are intersected by cross courses, is an opinion common in Cornwall, and for which good evidence appears: sometimes this happens only on one side of the cross course, as at Huel Creber mine, near Tavistock. Reciprocally, the cross courses are productive near the places where they cut the veins. When veins cross one another, it is supposed that the intersections are seldom enriched if the veins differ much in underlie.

Slides often contain ore, in the part between the separated portions of the veins which they divide and dislocate.

Theory of Mineral Veins.

There is, perhaps, no portion of geological science less satisfactory than the variety of opinions, and conjectures, which, till within a few years, constituted what was called the "Theory" of mineral veins. In no department of geology is it so difficult to observe accurately the phenomena which form the basis of reasoning, or to obtain from experience the data which ought to limit and direct speculation. A short inspection of a mine, with the disadvantage of confused lights and noises, and explanations hid in a phraseology of very difficult interpretation, leaves on the mind a feeling of disquieting disappointment. The important facts of the intersection of veins are not seen; the segregations of ore in a vein, the change of the contents with the change of ground, with the depth, the underlie, and other influential conditions, must all be taken on the affirmation of the agent, in whose office the stranger expects in vain to find a complete record of the subterranean operations, with all the scientific data which they have revealed. Dr. Boase was so impressed with these difficulties, that in his examination of the veins of Cornwall, with a view to understand their formation, he declined to enter the mines at all, preferring to trust his reasonings on the few phenomena in the sea cliffs, which he could accurately examine, than on the almost innumerable facts which the mining art has disclosed, only to be, in many cases, lost for ever to science. The want of a national system of mining records is now acknowledged, and ought to be remedied.* Werner's views on this subject are not unworthy of his high reputation. (See his work "On the Origin of Veins.")

* This subject has attracted the attention of the British Association for the Advancement of Science, who directed a representation to be submitted to the government. The result is a Mining Record Office.

Even under these extreme disadvantages with respect to the facts, the theory of mineral veins might have been more rapidly advanced, had a right method been followed in the interpretation of them; but this subject fell under the general misfortune of geology, and was considered rather as a boundless arena for Neptunists and Plutonists, for Wernerian and Huttonian controversy, than as a storehouse of more curious truths than those contained in the rude notions of injection by heat, or solution by water.

In the unfortunate dissociation of reasoners and observers, which is not even yet remedied, the imperfections of the closest speculations were too apparent to the miner to leave him the slightest confidence in the explanations proposed; and when, moreover, to every general rule regarding the position and contents of veins, gathered from observation, and seemingly established, further experience brought exceptions, how can we wonder that practical men gave up the problems as desperate, rejected mechanical and chemical causes altogether, and, resolute in ignorance, believed the veins to be contemporaneous with and an essential part of the stratified rocks, *in whose history they felt no interest?* This was the "vulgar notion" in the time of Agricola (1556), but it has been revived among men of science in the 19th century.

This, in fact, is the fundamental question in the theory of mineral veins; and though the state of knowledge on the point is so much advanced since the days of Werner and Playfair, that Macculloch thought, and most geologists feel, the question to be completely decided, we do not think it unnecessary to substantiate the truths which they have rather assumed than proved, and examine the objections which they neglected.

Veins are posterior to the Rocks which they traverse.

Werner, in his definition already given, assumes as a truth, that veins are of posterior date to the rocks which they traverse, *because they fill fissures in them*, but he was aware of the opinion which had, and still has, supporters, that veins were formed at the same time, and are of the same age, as the rocks in which they occur. He takes the trouble to examine this point, and to establish the origin of veins by the filling up of originally open fissures as a fundamental point of theoretical and practical importance. He offers *nine proofs* in support of this unequivocal statement, hoping to "remove all doubt of its truth from the mind of every intelligent and unprejudiced geognost and miner." These proofs, though not very skilfully managed, appear sufficient to establish the conclusion as far as regards the phenomena described by Werner, and commonly met with in mining experience. Practical miners, in all but a few districts, seldom express the slightest doubt of the truth of the Wernerian postulate, from which we have here retrenched the part which affirms that the veins were *open in the upper parts.*

Those who in modern times reject this origin of veins, and revive the notion that they are contemporaneous with, and a part of the rock formation, in which they lie, are influenced in their views, first, by the difficulty of explaining, according to simple mechanical laws, the displacements which, on the Wernerian supposition, the fissured rocks must have experienced; secondly, by the admitted fact, that there is some general, and often some special, affinity between the contents of the vein and the nature of the including rock; thirdly, there are cases in which substances of the same nature as those in veins, and combined in the same manner, are found in cavities which are unconnected with veins.

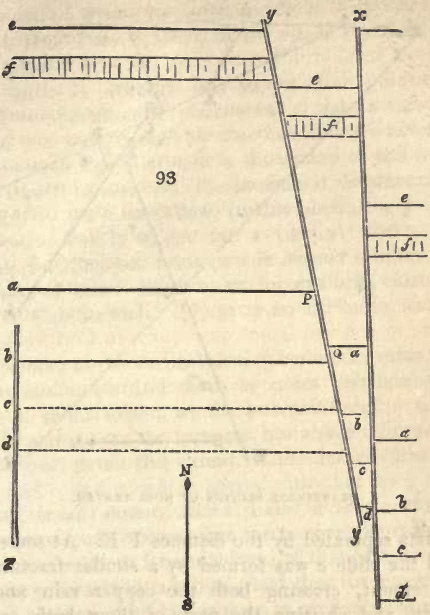
These circumstances have been regarded as of much importance, especially in Cornwall, where numerous veins, occurring under various circumstances, and inclosing a vast variety of minerals, have been worked extensively to unusual depths, by men of great experience. If, then, in a country so favourably circumstanced, we find the theory of veins halting at the first step, we must admit that the general argument by which this step is fixed, is far from clear, or be prepared to encounter peculiar difficulties in the application of it to Cornwall. That the general argument is not really defective, we shall endeavour to shew, by examining the three classes of objections which have been referred to.

1. The mechanical difficulty of explaining the movements of the masses of rock in which the veins lie, is more considerable in Cornwall than in any other mining country yet investigated. In Vol. I. p. 40. we have given a sketch of the usual relation (*a, b, d, e*) of the planes of displacement to those of stratification, and an example of the contrary (*c*). Now this latter case, so rare in general, is not unfrequent in Cornwall. Another cause of difficulty is the excessive abundance of the veins, and the variety of direction, inclination, and inequality of apparent displacement, which they manifest.

The accompanying plan and section of Huel Peever mine will explain many points peculiar to the Cornish veins.

On the ground plan it will be seen that six parallel courses (a tin vein, two copper veins, an elvan course, and two "slides") are "shifted" to the south by the cross course *y*, and again still further to the south by the cross course *x*, each through the same horizontal space.

In the vertical transverse section (taken from north to south), it is seen that the two "slides" *c* and *d* pass through and interrupt, in their inclined courses, both the copper vein *b*, which is inclined in the same way (to the north) as the slides, and the tin vein *a*, which is inclined the contrary way (see the points marked A, B, C, D, G): also, it is seen that the copper vein *b* passes through and displaces the tin vein *a* (compare the points F and E); moreover, it appears that, excepting the displacements from A to C, B to D, F to E, and at G, there is no irregularity, the divided parts of the vein being respectively parallel.



GROUND PLAN OF HUEL PEEVER.

a, a′, a″. Tin vein worked.
b b′. Copper vein, called "John's Gossan."
c. North "slide."
d. South ditto.
e. Copper vein.
f. Vein of clay. ("Elvan.")
x, y, z. Cross courses.

The ordinary explanation is that the tin vein, now appearing in four parts, *a*, *a′*, *a″*, *a‴*, is the oldest vein, and was formed in one straight line; after its formation the copper vein *b b′* was formed by filling a straight continuous fissure, which was made by violent fracture of the mass of the rocks across the tin vein. This was accompanied by a dislocation of the rocks inclosing the tin vein; so that the line was broken and

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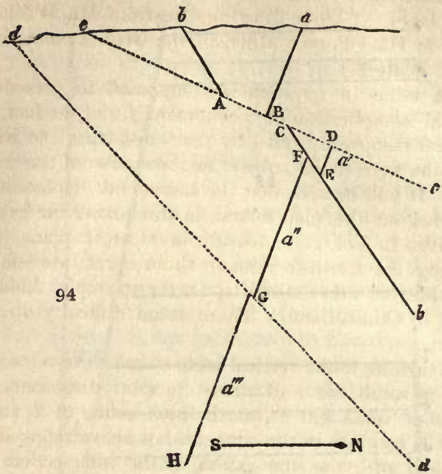


TRANSVERSE SECTION OF HUEL PEEVER.

the parts separated by the distance F E. At some later period the slide *c* was formed by a similar fracture and displacement, crossing both the copper vein and the tin vein, and shifting the parts of them both, so that the copper vein was divided into two parts, *b* and *b′*, separated by the interval A C; and the tin vein again divided and its parts *a* and *a′* separated by the interval B D (which is equal to A C). At the same or some other time, the slide *d* produced a slighter effect on the tin vein *a* at G. What other effects may have accompanied the other intersections, which are indicated as possible, viz. *c* and *d*, *b* and *d*, the locality does not shew.

Finally, after all these fractures, three fissures in a north and south direction, *x*, *y*, *z* in the ground plan (not seen in the vertical section), have been formed across *a*, *b*, *c*, *d*, *e*, *f*, and have been accompanied by dislocation in a horizontal direction along nearly vertical planes. (These drawings are from Mr. William's paper on Huel Peever Mine, in the Geol. Transactions, vol. iv. plate 7.)

The mine in question was supposed to present an unusual complication of phenomena; and, in fact, the practical men were baffled by the "accidents" to which the veins were found subject in the course of the workings. It will be seen that the horizontal displacements indicated on the plan follow, in this plane, the general law given in Vol. I. p. 40. for a vertical plane, thus bringing the Cornish veins in this respect into analogy with those of other districts, as, for example, Aldstone Moor, in Cumberland. There is no difficulty in this respect.

On turning to the vertical section across the veins from north to south, we find three apparent displacements: one to a small extent, at the intersection of *b* and *a*, which is contrary to the common law above referred to; a second, of twice the extent, at the intersection of *c* and *b*, and *c* and *a*, which agrees with that law; and a third, of small extent, where *d* and *a* meet, which is again exceptional. Now, that the movements supposed are possible, without inconsistency, in this case, any one can satisfy himself by a model; and that the result, *i. e.* the *new position* of all the *masses*, is perfectly explained by such movements, is obvious from the following facts: first, the displacement of each of the veins *b* and *a*, on the line of fissure *c e* is *equal;* in the next place, the divided parts retain their *parallelism;* and, which is not of least importance, they agree in their characteristic contents.

Such cases do not oppose, but strongly confirm, the opinion that veins are posterior to the rocks which they traverse, and of unequal antiquity as compared with one another. But it must not be thought that the Cornish geologists, who have revived the opinion of Stahl, that the veins are contemporaneous with the rocks, have no stronger case than that of Huel Peever.

Mr. Henwood, in his communication to the Geological Society (Nov. 1832), mentions several instances of remarkable intersections, some of which are, and others are not, easily explicable by the supposition of real movements in right lines.

Thus, if, "in Weeth mine, two cross courses are traversed by the same east and west lode, and one is heaved to the left, and the other to the right," (in a horizontal plane,) this would necessarily happen if the cross courses dipped in contrary directions, and the movement on the plane of dislocation were vertical. In all such cases, precise and complete measures are necessary, to enable a candid inquirer to form a satisfactory opinion as to the mechanical solution of the problem of displacements involved in the data; and such a case Mr. Henwood presented to the Section of the British Association at Liverpool. Most of the phenomena described in that communication were capable of explanation by simple movements in right lines, but some were not; particularly the case of two veins, dipping in opposite directions, and yet heaved *the same way*, contrary to the mechanical necessity of the case, had the movement been real. In such cases, angular movements of the masses, which are known, by examples of common faults, to be *real causes*, may be appealed to.

It is impossible now to enter into a minute examination of this and other such cases of embarrassment, which change their aspect when *a whole district of related veins* is submitted to consideration; but having examined many of the published examples of intersection of veins in Cornwall, it is our opinion at present that much of the difficulty has arisen from the incomplete description of the phenomena, and the division of the general problems belonging to a considerable extent of displaced ground, into a multitude of minor cases, the key to which is in their connection. There can be no doubt that the great mass of these phenomena are perfectly reconcileable with the hypothesis of real displacement of the masses of rock, and it appears to us that little is wanting to reduce the whole to understood laws, except a greater attention to the influence which the jointed structure of the rocks must be admitted to have exerted in modifying the result of mechanical movements.

In the plan and section of Tin Croft mine, given by William Phillips in his Outlines of Mineralogy and Geology, p. 165., one of two parallel copper veins is represented as sending off two branches *on one side*, probably into joints of the rocks. Had the veins there represented been traversed by a "slide" underlying to the south, the phenomena, now so clear, might have been rendered very difficult to comprehend. We have made models of some of the possible cases of real movement, the complexity of which in the case of the Cornish veins appears to us greater than any thing yet found in mining.

Turning from this district to others of less complexity, we shall see immediately the impossibility of a reasonable doubt as to the fact of veins now occupying what were fissures in the rock. In the mining districts of Wales, Derbyshire, Yorkshire, Cumberland, where sandstones, shales, coal, basalt, and limestones, alternate in one or more successions, and are all divided by the same vein, to which of these strata of unequal antiquity is the vein contemporaneous? When, on the opposite sides of such a vein, are seen the separated parts of large corals, and in innumerable cases of the small strings passing off from a vein, the division of shells like Producta, Euomphalus, &c.; all further discussion is useless, and the facts thus proved in cases free from complexity, are with justice employed to interpret, in other dictricts, results which are marked by additional influences.*

2. The affinity between certain rocks and the veins in

* But it is not now necessary to appeal to such evidence in districts distant from Cornwall, since Mr. de la Beche has discovered encrinites and other organic remains imbedded in killas (grauwacke), close to the walls of Great Crinnis copper and tin lode, — says Mr. Fox, in his Summary of Phenomena in the Veins of Cornwall, p. 25.—*Report of Polytechnic Society*, 1836.

them is real, and sometimes leads to an intimate union of their substance by mutual penetration. To this, considered as an objection to his theory of veins, Werner makes the following reply.

"The union between a vein and a rock, on some occasions, is so intimate as to give the appearance of their having been *melted together*, if I may so express myself." "In places where this peculiarity occurs, the rock has had a strong attraction for the substance of the vein introduced into the rent, and has become so intimately mixed with it, that they now appear to be one and the same substance; at least, it is not easy to mark a line of separation between the rock and the vein. This is particularly the case with veins of quartz and hornblende, when they occur in newer gneiss of a quartzy nature; but veins of pyrites in this rock do not present this appearance, which is, *upon the whole, a rare occurrence.* In general, the vein and rock are very distinctly *separated from each other;* and there are sometimes interspersed between them thin layers of an earthy matter called *besteg.* A vein is very seldom united to the rock so as to adhere intimately with it through its whole course; but this only takes place in certain parts." (*Werner on Veins*, p. 90.)

To this it seems only necessary to add, that in whatever manner the ingredients of mineral veins were placed in their present situations, it is not possible to doubt that the specific relations alluded to must have been manifested. Were all the mineral masses injected by fusion, as Hutton thought, there would be segregations, and peculiar arrangements, produced by the conditions of cooling, the conducting power of the rocks, and their inherent molecular forces. Were they introduced by solution, as Werner believed, what menstruum capable of dissolving such a heterogeneous mixture could be without power on the walls of the fissure, or some part of them? Were the elementary parts of the substance of veins raised by sublimation, molecular attractions would be exerted unequally by the different parts of the sides of the fissure; and if electrical currents were the agents of transferring the metallic substances to their peculiar repositories, the conditions of the rocks as to conduction of heat and electricity become of paramount influence. The specific affinities which the contents of one vein display to the different rocks which bound it (as in the lead mining districts of the north of England), when rightly viewed, offer a most convincing proof that the substance of veins was introduced among these rocks *after* they had acquired such conditions of hardness, position, &c. as to exert unequal powers in determining the arrangement of the substances presented to their influence.

3. Strings and branches of metallic and sparry substances, like those which occur in veins, but inclosed on all sides in rock, are of sufficiently frequent occurrence to demonstrate that not all mineral repositories have been *open fissures*, filled by depositions from above, as Werner taught, or by injection from below, as Hutton contended, or by mere sublimation, as other writers besides M. Necker have advanced on good though limited evidence. We have shewn, while treating of the "forms of igneous rocks," that such "contemporaneous veins," as Jameson properly calls them, have arisen from the same play of affinities as the spherical arrangements of the orbicular greenstone of Corsica; they are "segregations" of parts of a fluid compound, depending on circumstances which affect its transition to a solid state. Such results may be admitted to have happened with metallic veins, whenever the evidence is equally clear. They are admitted by some writers for some of the veins in Cornwall.

But yet, a general contemplation of insulated metallic and sparry masses, which fill cracks and other cavities in rock, will not allow us to adopt this as a general explanation. These cracks and cavities have existed *as such* in the limestones of the north of England, before the introduction of their crystallised contents. For some of these cavities are the inner hollows of bivalve shells, which shut close and have no opening (Producta); others are the closed chambers of cephalopodous shells (Orthoceras, &c.). Nor is it doubtful that many, if not all, the cracks and joints which, *near a metallic vein*, hold sulphuret of lead, or carbonate of copper, have been produced during the condensation of the stone, since we not uncommonly find them crossing and dividing the substance of shells and corals (Wensleydale) and fishes (Whitley quarry, near Cullercoats).

Upon the whole, therefore, whether the mineral substances occur in distinct regular *fissures*, occupy plane *joints*, lie in irregular *cracks* or holes of rock, or line secret hollows in *shells*—in all of these cases the existence of a cavity to receive the crystallised substances is demonstrated, as the most *ordinary* antecedent to the production of the mineral mass. It follows as a consequence, that *ordinarily*, when veins cross, and one passes through and divides the other, the "cross vein" is of later origin than that which is cut through. But as to the vein fissures having been originally *open* above or below, and as to the manner of their being filled, these points remain for further consideration.

Origin of Vein Fissures.

The theory of the origin of veins being thus to a certain degree insulated from that of the rocks in which they lie, the next thing to be determined is the origin of the fissures in which the metallic and other mineral combinations have been effected. The fundamental facts for this inference are the prevalent parallelism of directions of the several systems of veins which, in a given district, belong to successive periods of formation; the penetration of these fissures through a great variety of rocks; their length on the surface (some extending even several miles); their depth, which in large veins exceeds the range of mining enterprise; the displacements of the rocks which they divide; their various intersections and mutual relations. It is obvious that the inferences to be adopted from these data, will be trustworthy in proportion to the variety of sources from which they are gathered, and especially if the seemingly peculiar phenomena of vein fissures can be referred to general laws which extend beyond the mining districts.

Now that this reference to general laws can be effected, will appear evident from the consideration that similar parallelism of structural fissures, passing through various rocks for greater length than mineral veins, to unknown depths, with the same variety of mutual relations, have been found in other than mining countries, by the observation of rock dykes, and the symmetrical structures of rocks called joints, and cleavage. The most prevalent direction of the Cornish veins (east by north), is that of certain characteristic joints in a considerable portion of England, beyond the region whence the results contained in Vol. I. p. 65. were derived; and the lines of the great cross courses of the Penine chain, Flintshire, and Cornwall (north-north-west), are also coincident with a very general divisional structure of the rocks in most parts of Great Britain and several other parts of Europe. Mr. Henwood and Dr. Boase expressly state, that the cross courses and principal veins more or less "coincide with the lines of symmetrical structures by which all the rocks of Cornwall are divided." (Henwood, in *Mining Review.*)

The symmetrical structures of rocks, are, however, different from the fissures now filled by veins and rock dykes; for they are seldom *so continuous*, either in length or depth; they are almost universally unaccompanied by displacement of the side; and they often change their width, frequency, and other characters, according to the nature of the rocks. It is obvious, therefore, that it is not merely by the filling of joints of the rock that veins and dykes were produced; the rocks have been disturbed in position, opened to a greater extent than the original divisional structures, or else these last are only to be regarded as minor effects of great disturbing forces which broke the strata along the lines of vein fissures and rock dykes. The following remarks are intended to show that symmetrical divisional planes, such as joints and cleavage, are due to other causes than disruption of the strata.

1. It is a fact, that from divisional planes ranging for many yards or even hundreds of yards, and separated by wide intervals, to the fine parallel, almost invisible, *cleavage* of coal (called "cleat."), and of clay slate, there is an almost perfect gradation of structures, which have a definite relation to the different nature of rocks, while subject to the same mechanical pressures and movements. In coal, shale, clay slate, and laminated limestone, it is in vain to attribute these regular divisions to any thing but the molecular arrangement which explains the structure of basalt.

2. In different beds of rock, as shale, limestone, and gritstone, which alternate, it is not uncommon to find the slopes or inclinations of the joint planes to vary, nearly as in different beds of slate the planes of cleavage will deviate from parallelism.

3. The joints are, for the most part, not continuous through all these alternating strata, but in each rock are characteristic divisions which enter no other.

4. In symmetry, extent, and frequency, joints are not at all less, but rather more, remarkable at points far removed from axes and centres of disturbance of the rocks.

5. Near such axes of movement, many irregular fractures of the rocks occur, and predominate over the natural joints, which appear not uncommonly to have been obscured, closed up, or complicated by irregular pressures and cracks in such situations.

It follows from these considerations, that whatever analogy of direction may appear between the lines of mineral veins and those of the natural structures of rocks, this only indicates the influence which such *lines of weakness* would necessarily exert on the direction of *fractures* produced by mechanical pressure. Now, as, in addition to joints, many other circumstances, as the unequal loading of the parts broken, and the varying thickness of unequally resisting masses, &c., must have contributed to the weakening of parts of the crust of the earth, the want of *perfect* accordance between the joints and all the lines of vein fissures, is no sufficient argument against the anteriority and real influence of the former over the latter.

The curious circumstance, not uncommonly seen in the mining district of Aldstone Moor, of the change of the "hade," or inclination of the vein, in its passage through different rocks, is perhaps explained by this admission of the relation of vein fissures and joints. The veins which pass perpendicularly through limestone beds, acquire an inclination in the alternating shales, and they are usually wider in the limestone than in the shale. Now, in both of these circumstances, the vein fissures resemble common joints, which not uncommonly are more inclined and much narrower in shales, than in the limestone strata of the same district.

Another curious fact, noticed in Cornwall, appears intelligible by considering the disturbing force as having opened at once two parallel discontinuous natural joints; so that opposite the point where one fissure ended, the other became open enough to receive substances of the same kind, and thus, as the miners say, to "splice" the vein.

All the principal circumstances which attend the dislocations of the strata along the planes of mineral veins, are equally witnessed in the cases of common rock dykes, and faults; the same general laws as to the relation of planes of strata and planes of dislocation apply, with similar exceptions; nor are there wanting in all these cases, proofs of the fact that some of the fissures have been subject to more than one movement. In mineral veins this is manifested by the striated surfaces of rock and veinstones ("slickenside"); it equally appears on the lines of disturbed strata (coal shales, carboniferous limestones), and with equal variation and confusion of direction, so as in many cases to suggest the probability that the great movements were, as indeed could hardly be otherwise, complicated with many displacements of small masses in different directions. In some instances, as already explained (Vol. I. p. 42.), the striation is in one only direction, marking a great simplicity of movement: this is also the most common case of mineral veins.

Whatever difficulties these phenomena may be thought to present, they are common to all cases of displaced strata, and must be parts of one general investigation. In this sufficient progress has already been made, to assure us that, when the data and measures necessary to form a right conception of the conditions are furnished, the mechanical problems of displacement are not beyond solution.

Filling of the Fissures.

We are thus conducted to that point in the history of veins, which was reached by Von Oppel (in 1769), and are stopped by the same impediment. In his Essay on the Working of Veins (quoted by Werner), he says: — "The natural structure of the globe seems to show us, that after the formation of the primitive and principal secondary mountains, they had suffered great desiccation, and been exposed to violent shocks. In consequence of these changes, the rocks and mountains, which formerly composed one continuous mass, were split asunder: whilst this took place, it might easily happen that one of the rocks split from the other without ceasing to touch it; or these parts might be separated from each other, leaving between them open spaces, which were afterwards filled up, in part at least, with different mineral substances. The greater part of these grand events belong to that part of subterranean natural history, which can only be elucidated by a consideration of the facts which the earth presents to our view; *for all these great revolutions took place at a period long before the globe became habitable to the human species.* But whether fissures and veins were actually formed in the manner we have described, or not, it is no less true that this manner of representing their mode of formation, and the relative situation which they bear to one another in the mountain, *is the most simple way of accounting for them.* It explains the uniform law of their formation both in a general and more particular manner, and, consequently, *we shall admit it as the real one.* This hypothesis would be still more satisfactory to the naturalist, if it were equally easy for him to conceive how a new mineral substance could be formed in these fissures, of a nature different from the rocks in which the veins occur."

One of the early attempts to conquer this difficulty is that of Lehman, who deserved more attention than Werner's somewhat contemptuous notice.

" What is called a rent, is an open fissure in a mountain, which has been produced by a division of the rocks; and veins are, in my opinion, nothing but fissures which have been filled by nature with stones, minerals, metals, and clay—in short, which are of a very different nature from the rock itself." Farther on he says,—" The veins which we find in mines, appear to be only the branches and shoots of an immense trunk, which is placed at a prodigious depth in the bowels of the earth; but, in consequence of its great depth, we have not yet been able to reach the trunk. The large veins are its principal branches, and the slender ones its inferior twigs. What I have said, will not appear incredible, when we consider, that in the bowels of the earth, according to every observation, is the workhouse where nature carries on the manufacture of the metals; that from time immemorial she has been working at, and elaborating their primitive particles; that these particles issue forth, *in the form of vapours and exhalations*, to the very surface of the globe, *through the rents*, in the same manner as the sap rises and circulates through vegetables, by means of the vessels and fibres of which they are composed." *

Another effort to penetrate the mystery of metallic

* Lehman, Abhandlung von den Metalmüttern und der Erzeugung der Metalle. 1753, quoted by Werner.

depositions, was that of Werner, who, in 1791, gave what he considered a "New Theory of Mineral Veins," of which the principal points of novelty are, the application of the phenomena of intersections to determine the *ages* of veins, and the hypothesis of aqueous solution for the filling of the fissures. In proof that the fissures of veins were filled from above, Werner mentions the occurrence of rounded pebbles at the depth of 180 fathoms in the vein Elias in Danielstollen at Joachimsthal, and similar instances in the Stoll refier near Riegelsdorf in Hessia, and in Dauphiné.

His notion of the manner in which veins were filled, partakes of the errors which belong to all the Wernerian hypotheses of the origin of mineral masses. He says, —"The same *precipitation* which in the humid way formed the *strata* and *beds* of rocks (also the minerals contained in these rocks), furnished and produced *the substance of veins;* this took place during the time when the solution from which the precipitate was formed, covered the already existing *rents*, and which were as yet wholly or in part empty, and open in their upper part." *

The Huttonian hypothesis of the earth's construction, opposed in almost every point to that of Werner, conducted naturally to a different interpretation of the same facts. The fissures were produced by forces depending on subterranean heat, and were filled by injection like rock dykes; and the parallel bands in the vein, which Werner ascribed to *successive aqueous deposition*, were referred by Hutton and Playfair to *successive igneous injection.* In support of this explanation, the acknowledged impossibility of solution in water of native, sulphuretted, and oxidised, metals, and many of the veinstones, was alleged, as fatal to the Wernerian but favourable to the Huttonian view.

The complicated phenomena of veins led some English

* On Veins, p. 50.—See also p. 110. for a further development of this very crude notion, mixed with some very ingenious suggestions, and important views of the relations of geology and mining.

writers, who admitted the posteriority of veins to the rocks which inclose them, to suppose their contents to have been collected from the neighbouring strata, by some peculiar process of segregation, depending on electrical currents. Thus it was supposed the successive depositions, and peculiar positions of the various substances which occur in veins, might be accounted for.

Lastly, the vague suggestion of electrical agency, in depositing the materials of mineral veins, has been reduced to a regular system by Mr. Fox, who, uniting the knowledge of veins to a zeal in conducting ingenious experiments which has led to most valuable results, has successively matured his views and advanced his experiments, till they have attracted very general attention. Perhaps the most complete account of his hypothesis is that which appeared in connection with a valuable collection of facts regarding mines, in the Report of the Polytechnic Society for 1837.

In this paper, Mr. Fox assumes as sufficiently proved, the origin of fissures, from various causes, and at various intervals, and the enlargement of them from time to time; the progressive filling up of these fissures; and their penetration to great depths and regions of high temperature. In such fissures, he shows the probability of the circulation of heated water by ascent and descent; and the deposition of quartz and other earthy substances in cool parts, which had been dissolved by the water in hotter parts. In such fissures, filled with metallic and earthy solutions, the different sorts of matter on the sides must necessarily produce electrical action, which might be exalted by the peculiar distribution of temperature. The currents of electricity generated would pass more easily in the fissures than through the rocks, and in directions conformable to the general magnetical currents of the district. These would be east and west, or somewhat north or south of these points, according to the position of the magnetical poles at the period when the process was going on. Electrical currents thus circumstanced, would deposit the bases of the decomposed earthy and metallic salts on different parts of the rocky boundaries of the veins, according to the momentary electrical state and intensity of the points; in which conditions the *nature and position* of the rocks would be influential. When by such processes particular arrangements had happened, new actions might arise, and secondary phenomena, such as the transformation of ores, *without change of form*, which are otherwise very difficult to understand; lateral rents might also be filled by virtue of these new actions, even though they were not in the most favourable lines of electrical circulation.

The general hypothesis being admitted, it appears to follow, that the observed influence of cross courses on the quality and abundance of particular accumulations of ore in the veins which they divide, affords strong ground to believe that, in such cases, the depositions of these ores was subsequent to the displacement of the vein fissure by the cross course. It appears to be Mr. Fox's opinion, that the clays in the flukans and cross courses were introduced mechanically, and that they affected, in a particular manner, the metallic distributions.

Not the least striking among the arguments in favour of Mr. Fox's electrical theory of mineral veins, is the fact, that he has formed experimentally many well defined metalliferous veins by voltaic currents, operating under circumstances expressly arranged in imitation of those which really occur in Cornwall. (See Reports of the Newcastle Meeting of the British Association, 1838.)

Recapitulation.

In considering these various views of the repletion of mineral veins, it must appear evident that some things at least are very probably established; the successive enlargement of some veins, the progressive repletion of most of them, and the influence of general polarities in the distribution of, at least, the crystallised materials. The more closely the investigation is made, the less certain appears the connection *in time* between the production of the fissure and its repletion. If the relative ages of *vein fissures* may be known by their intersections, this does not so clearly apply to *their contents;* and thus we find it quite possible that no long geological period, such as Werner contemplated, may have intervened between the older and the younger vein-fissures of a given district.

It certainly appears at present unsafe to adopt any one of the views here noticed *exclusively*. Sublimation and re-crystallisation of metallic matters (whether pure metals, sulphurets, or oxides) are common phenomena; and the passage of veins downwards to heated regions is too probable to render it doubtful that such operations have sometimes contributed to fill the fissures of rocks. Mr. Patterson's experiment of the influence of steam in causing the *sublimation of galena* in an earthen tube heated in the middle (*Phil. Journal*, 1829), is an important illustration.

The deposition of blende, sulphuret of iron, carbonate of lime, sulphate of barytes, quartz, &c. in cavities of organic bodies, and in other situations, by the agency of water, must exempt Werner from the charge of *absurdity* in attributing to aqueous solution some of the phenomena of the repletion of mineral veins; but, as a general explanation, his system is of no value.

Nor does it appear, at present, just to attribute a much larger measure of success to Playfair's application of the Huttonian hypothesis. It is, indeed, certain, in many instances, that metallic impregnations are mixed with rock dykes, or lie in veins by the side of them. Some veins may have been filled by injection, especially such as appear very simple in their structure, uniform in their composition, and wholly independent of the neighbouring rocks in the distribution of their contents. Such veins there are; but this speculation does no *well* meet the cases of many parallel bands in a vein, segregations in lines of particular rocks, and in closed cavities of rocks, the mixture of fusible and infusible substances, and the variation of the contents of veins according to *their directions*, and other characteristic facts.

All of these excepted facts, indeed, appear indicative of other agencies and polarities accompanying and governing the deposition of metallic ores. It is difficult to doubt the truth of the views which ascribe these peculiar and characteristic arrangements to electrical action, and perhaps the principal problem now remaining, is to determine whether, as Mr. Fox believes, the electrical currents were voltaic, generated by the chemical action of particular solutions on particular substances, or thermo-electric, depending on the application and conduction of heat. As far as experimental research goes, the labours of Becquerel, Crosse, Fox, and Bird appear at present to give the advantage to voltaic electricity as the agent of arrangement in metallic deposits. The other source of electrical power has been less inquired into in this respect; and yet, when we consider the facts of the communication established by metallic veins of different conducting power, from the cold surface to the hot interior of the globe, and recollect that permanent differences of subterranean temperature are commonly observed among contiguous rocks (as the killas and granite of Cornwall, which differ 3°), it is difficult to check the belief that thermo-electric currents, however weak in intensity, are *now* important in their agency, and may *formerly* have been much more so.

In these remarks we have chiefly in view the *arrangement* of the substances in a vein; the *accumulation* of these may be due to quite different causes. In some cases it really appears that a complete account of the accumulation of the substances is very difficult to collect, except we call in successively the solvent powers of water and heat. The formation of sulphurets is obviously one of the most important of all the facts requiring explanation in mineral veins, because a very large proportion of metallic ores (tin is the principal exception) appears in this state. Heat, by sublimation, sulphuretted hydrogen, by decomposition of metallic salts, may give us the sulphurets; but, in the latter case, from what prior condition is the sulphuretted hydrogen derived? Mr. Fox proposes the *decomposition of other sulphurets,* by electrical action. Thus we make no advance, and again turn to the simple action of heat, which, in like manner, stops at the *origin* of these sulphurets, and only accounts for their *transfer* from the deeper parts of the earth. This, perhaps, measures our possible knowledge as to the *origin* of the metallic ores. They have been *transferred* from the interior of the earth toward its surface, principally along the fissures opened by violent movements.

But this conclusion does not necessarily apply to the sparry contents of the veins. Aqueous solution of most of these is possible, but of some it gives no sufficient account. Some, as salts of lime, *abounding in a limestone* country, may reasonably be attributed to the action of water passing through the rocks; others, as quartz, may be thought to require much heat for their solution; the clays and rolled fragments mark mechanical action of water; and thus, finally, it appears that the present aspect of mineral veins is the result of many secondary chemical, electrical, and mechanical actions, the general antecedent to which is the influence of a high temperature below the surface of the earth.

CHAP. IX.

MODERN EFFECTS OF HEAT IN THE GLOBE.

To know the temperature of the interior parts of the globe at the present period, and the effects depending on its condition in this respect, is important, as furnishing one, and that, perhaps, the most instructive, of the elements for computing the changes which have, in earlier times, affected its structure and configuration, and varied its adaptations for organic life. By combining such knowledge of the subterranean parts of the earth as they now are, with inferences concerning more ancient periods, we are to seek the laws of action and variation of terrestrial heat, and, with the help of chemical and mechanical philosophy, to arrive at a general contemplation or "theory" of this part of geological science. Once well established, such a "theory" will be fertile of *deductions* bearing on all the known phenomena of organic and inorganic action: the *recorded facts* of geology form, on the other hand, a parallel series of terms, which involve the same elements: by comparison of these two scales, the progress made in the interpretation of nature will readily appear, and the lines of further research will be clearly indicated.

The phenomena indicative of the presence and degree of heat below the surface of the earth, are either such as mark its ordinary and regular state, as HOT SPRINGS, which, with a few exceptions, are not known to vary in their temperature, and VOLCANOS, which mark, in their epochs of critical action and their periods of repose, the measure of the intermitting agencies connected with their origin, growth, and decay. The conclusions which arise from these cognate phenomena may be further tested by *experimental inquiries* into the statical temperature at small depths below the surface of the earth.

Volcanic Action.

Volcanic action, considered in its full meaning, includes, perhaps, the largest class of phenomena, attributable to one predominant agent, which falls within the province of geology. These phenomena are the more interesting and instructive, because they extend through an immensity of past duration, with many variations distinctly related to geological and historical time. The facts known by history and tradition respecting particular vents of subterranean fire, go back to the origin of history and civilisation, and other phenomena of the same volcanoes are undoubtedly to be referred to a part of the scale of geological succession, corresponding to the forms of plants and animals which lived and died before the present races occupied the surface. Each volcanic mountain has its own peculiar history, its accident of origin, its law of progressive increase, its period of inevitable decay; it is a monument more venerable than the pyramids; recalling, by its mysterious agitation of the fertile plains around, the remembrance of movements affecting other lands and seas than those on whose boundaries volcanic fires are now excited.

What augments the interest naturally attached to problems regarding the long duration and varying energy of volcanic fires, is the completeness of the series of phenomena which, taken collectively, they present. New vents are opened in every few years to show us the origin of volcanic accumulations on the land or in the sea; an hundred ignivomous mountains bring up to the surface abundant examples of substances most instructive on points which otherwise could only be sources of vain conjecture; and the last stage of these frightful disorders of nature is seen in many districts where, only at particular points, mephitic vapours rise to darken the smiling picture of general fertility.

Origin of Volcanos.

A mountain which has long been silent, and on whose slopes the cultivation has spread for ages, is yet the centre of great subterranean disturbance, shaken by earthquakes, and surrounded by hot springs and sulphureous exhalations. It cannot be known, from such phenomena alone, whether the volcanic energy of this particular region is sinking slowly to the entire decay, which the perishing craters of the Eifel indicate, or reawakening to violent efforts, like those which Vesuvius made in the year 79 of our era, after many centuries of entire repose, while the older crater of Monte Somma was falling in decay.

The renewal of action in an old volcano, after a long period of repose, may be looked upon as exhibiting, in a considerable degree, the phenomena which accompany the first origin of a volcanic vent. Earthquakes, subterranean noises, the bursting forth of new springs, and the suppression of old sources, are symptoms of a particular kind of subterraneous disturbance, of which they record the violence, and in some degree moderate the effects. Volcanic *forces* are in action wherever such phenomena appear; and, unless the imprisoned powers acquire an extraordinary intensity, these are their only effects; volcanic *eruptions* are the consequence of forces which have accumulated beyond the relief afforded by displacements of the crust of the earth.

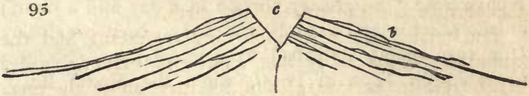
The terrific aspect of a burning mountain, and the immense volumes of melted rocks and scattered ashes which remain as measures of its fury, affect the imagination too strongly; and in this scene of temporary violence we forget the less marked, but really important, changes occasioned by the disturbance of interior temperature, which in sudden earthquakes, or more gradual and extensive changes of position among the masses of matter, is slowly modifying the aspect of the globe.

But, independent of the information to be gathered from the renewed activity of particular volcanos, like

Etna and Vesuvius, whose changes of condition are matter of history, the prolific energy of heat has raised up islands in the sea, and mountains on the land, within our own days; and though these new volcanos are always near to the situation of old ones, and are really only new chimneys to the same subterranean fires which those conducted to the surface, the circumstances of their origin are very instructive.

In what form does the ground open for the formation of a new volcanic vent? This question has been answered by Von Buch's hypothesis of "craters of elevation," which, taken as the *origin* of a volcanic mountain, are described as being formed by the uplifting of the ground in a dome-shaped or conical elevation, with a central aperture. The correctness of this opinion has been disputed by Mr. Lyell, and both observation and calculation have been employed to determine the truth. What is now seen of volcanic mountains in general, proves them to be accumulations of ashes and lava currents, heaped in a conical shape round a central aperture. Supposing the aperture *made,* it is obvious that lava streams from its edges would flow only to limited distances, and scoria and dust would fall in showers round the opening: and thus every volcanic cone would show, in a vertical section, as *fig.* 95., layers (*l*) more or less irregular, sloping

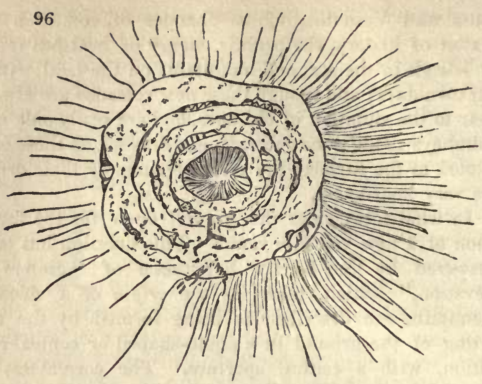
95



each way from the crater (*c*). In a horizontal section, the *layers* of ashes and *streams* of lava would be distinguished, as in *fig.* 96.

[The dotted parts correspond to the depositions of ashes falling all round the crater, and enveloping the lava currents, which ran down different sides of the mountains at different times. In one part the lava is seen filling a cross rent in the mountain, like a dyke of older rocks.]

96



Mountains thus constituted have been, doubtless, formed by successive eruptions; they may be called "craters of eruption;" but still the question recurs, — What was the *origin* of the opening through which those ejections began, which in their continuance have formed craters of eruption?

In several cases which have occurred within the reach of authentic history, eruptions on Etna and Vesuvius have commenced in the opening of a *fissure* through the previously aggregated masses of volcanic substances. This happened in 1538, when the Monte Nuovo rose (the greater portion in a day and a night) on the shore near Puzzuoli, which had been previously (for two years) disturbed by earthquakes. Fissures appeared on Etna in 1669, when the Monte Rossi, which is a double cone of 450 feet in height, was formed by explosion, and lava currents ran down the mountain.

The year 1759 witnessed the formation of a new volcanic vent, and the accumulation of the new mountain of Jorullo (1695 feet high), west of the city of Mexico. According to Humboldt's relation, "a tract of ground from 3 to 4 square miles in extent rose up in the shape of a bladder;" and the bounds of this convulsion are still distinguishable from the fractured strata. This important statement has been controverted by the opponents of Von Buch's hypothesis of "Erhebungs Cratere," and defended by its favourers; and if Humboldt's account remains the only authority for *such* a mode of origination of a crater on land, we must also remember that it is the only authority for *any* mode of origin of the opening of a new volcanic region.

But it may be asked,—Are there no characteristic arrangements of the volcanic rocks, which may be employed to determine whether they were accumulated in a level, or in an inclined conical position? are there no characters of form or fissures by which a mountain of elevation can be distinguished from a crater of eruption? It is maintained by De Beaumont and Dufrenoy that there are. If we attend to the forms necessarily assumed by lava flowing from the crater of a volcano, we shall see the almost impossibility, that the melted matter should flow equally on all sides, so as every way to invest the cone with a concentric strata of rock. Wherever the crater is lower, or the slope of the cone depressed, there the liquid would be directed, and long streams (or coulées), not zones of rock, be solidified. If then, in any case, the structure of volcanic masses is such that the distribution of once melted rock is concentric to the conical surface, and not in narrow streams parallel to the slope, such a mass of rocks may be thought to have been raised by expansion, by elevation from an originally nearly horizontal strata. If, indeed, we suppose the lapse of immense time, many streams of lava may successively flow down, and cover the whole conical slope; but not regularly, nor with that uniformity and mutual union here meant by the term concentric sheet of rock.

The cases are few in which this arrangement of the volcanic layers appears. The insulated hills of trachyte ("domite") near Clermont, in Auvergne, are supposed by Dr. Daubeny to be of this nature; the Mont d'Or and Plomb du Cantal have been specially quoted and illustrated in proof of Von Buch's speculation, by MM. De Beaumont and Dufrenoy. Distinguishing clearly, in their prefatory remarks, between the enveloping of a mountain slope by many streams of lava, and the elevation, with fractures, of broad floors of rock, into a conical mass, they attempt, by a consideration of the structure, form, and fissures of these mountains, to determine rigorously to which of the two cases they belong. In this argument the fissures yet existing in a volcanic mountain are an important part of the data; — it requires no great exercise of calculation to see plainly that, on the supposition of a conical elevation, the fissures will grow wider and wider, till they meet in a large subcentral hollow; and the sum of their breadth will vary as the inclination of the cone; and it depends upon a careful examination of the district whether these conditions be fulfilled. In the opinion of the able geologists quoted, the state and appearance of the sheets of rock which concentrically form the Plomb du Cantal, is such as to agree with the hypothesis, which, besides, is supported by an examination of the nature of the rocks. The Plomb du Cantal, they observe, is in no manner assimilated to a denuded cone of eruption: this supposition of its origin is, on several accounts, inadmissible; it is, on the contrary, by all its characters, the *result of elevation* operated on a great basaltic plateau, resting on trachyte. The group of Mont Dor requires, on this hypothesis, several centres of elevation; on Mr. Lyell's view, as many points of eruption.

The conclusion of Dufrenoy and De Beaumont has been objected to by Mr. Lyell on various grounds, principally the unequal thickness of the presumed plateaux of volcanic rock now found sloping from the Plomb du Cantal; for these, according to Prevost, are thickest toward the centre. It is satisfactory to refer to an independent inquirer, very competent to deliver a just decision on all the bearings of this subject. Professor Forbes, visiting Auvergne in 1835, directed his attention to Von Buch's hypothesis, and has recorded the result (*Edinb. New Phil. Journal,* July, 1836). He noticed the radiation of valleys from the Cantal, their narrowing from the centre of the elevation outwards, and their *wanting lateral valleys.* These radiating valleys, so numerous, from a single mountain, appear to have originated in fissures of disruption. The alternation of "stratified" tufa, with trachyte, under a capping of basalt, in the slopes of the mountain, is an argument of weight with professor Forbes, and leading to the same conclusion. "Upon the whole," says this careful observer, "it seems to me that the evidence of earthquakes subsequent to the deposition (in whatever way) of the Cantal and Mont Dor, is a fact so indisputable as to render the argument about craters of elevation to a great extent merely verbal."—"There seems, therefore, so much of probability, and so little of extravagance, in Von Buch's theory, that we wonder how it could possibly have given rise to such animated opposition."

Let us turn from volcanic districts to others in which stratified rocks have been subjected to vertical displacement, in order to see in what forms the dislocated rocks are combined. Are there in such rocks "hollows of elevation" such as may be compared with the *erhebungs cratere* of Von Buch? It appears that there are such elevations, unless, with regard to the lake of Laach, we reject the obvious inference from its general figure, and are prepared to doubt the exactitude of the description of the "valley of elevation" of Woolhope. Such cases are, however, rare; they seldom occupy an exactly, or even approximately, circular area: the Woolhope valley is elongated, the Laach crater imperfect; the valley of elevation of Kingsclere is very little allied to a conical mountain; Greenhow Hill, in Yorkshire, though a double or transversely divided elliptical elevation, is, perhaps, as good a case in point as any that can be mentioned in England, to show the analogy which really obtains between the elevation of ancient strata and that of some modern volcanic tracts. To what extent the admission of this analogy bears on the origin of particular groups of mountains remains to be seen, but it seems probable that most of the volcanic mountains are, like Vesuvius, Etna, and Stromboli, *craters of eruption,* while a few may be better explained by a general or partial elevation, at the origin or during the continuance of their action.

It must not be thought that the discussion regarding the first opening of volcanos is unimportant: the history of ancient elevations of the strata is closely connected with that of modern earthquakes; and the occurrence of volcanic fires along mountain lines is a circumstance very intelligible, upon the supposition that they were caused by the opening of the ground along a great fissure, and perhaps hardly to be explained otherwise. If volcanic regions, arranged in line, owe their origin to the rupture of the ground along that line, its length, and the degree of displacement of the rocks on its sides, are measures of the repressed force which at length found vent. "Volcanos in line," as Von Buch calls them, are thus connected with the traces of the grandest movements which the crust of the earth has experienced; and those who contend against the origin, by elevation, of single volcanic hills, oppose the doctrine of mountain elevation by one or a few violent struggles of nature, anterior to volcanic eruptions along them, and attribute the elevation of ranges like the Andes to many successive efforts of the volcanic action seated below them. The further discussion of this subject is part of a general inquiry, comprehending alike the modern and ancient movements of the land, which will be found in the next chapter.

Volcanos in Action.

Earthquakes, and the other premonitory symptoms of a volcanic crisis, are succeeded by eruptions from conical hills which have previously yielded passage to the fiery floods pressed upwards to the surface, from new orifices on the flanks or at the base of ancient cones, or from situations where volcanic action is a novelty. The effects vary according to the diversity of conditions. The materials issue in the form of melted rocks (lava), or are driven up in the state of ashes and dust (scoria, &c.), or burst forth as gas or steam. The lava, lifted by great mechanical pressure from some depth in the earth, rises in the tubular passage of the mountain toward its summit; and if the sides of the cone are strong enough to resist the accumulating pressure, it may even overflow the top, as has happened in the Peak of Teneriffe, to whose very summit Humboldt traced a stream of vitreous lava. But, generally, the slowness with which an eruption proceeds, is such as to allow of the lava making for itself lateral passages to the surface, on the flanks of the mountain, through fissures which yield to the pressure of the column above, or are opened by earthquakes. Such lateral eruptions have raised many minor cones on the slopes of Etna, and round the base of Vesuvius. Portions of the lava which enter fissures in the sides of the mountain, and are consolidated therein, may be compared to the dykes of the older pyrogenous rocks.

Lava, whatever be its chemical composition, puts on very different appearances, according to the circumstances which accompany its consolidation. The main circumstances which thus modify its aspect, are the volume of melted rock, the exposure of its surface to air or water, the nature and position of the surface on which it rests. Prismatic structures seldom appear in the rocks, except where the mass of the lava was great; cooled in sea-water, the lava of Torre del Greco became more dense than that which was cooled in air, and assumed rudely prismatic structures. On sloping surfaces it is found that the cellular cavities, common to lava which is cooled in the air, are elongated in a direction parallel to the slopes,—an effect clearly intelligible by considering the viscidity of the moving mass, and easily imitable by art.

The minerals which enter into the composition of lava are, as already stated (p. 83.), chiefly felspar, augite, and titaniferous iron. But besides these, many varieties of substances are produced in a crystallised state during the cooling of the fused mass; and, as is commonly observed among the old rocks, such as granite and basalt, these occur most plentifully, and in the finest crystallisations, in cellular cavities and small fissures of the lava. Eighty-two species of minerals are enumerated in a catalogue of the products of Vesuvius by Monticelli and Covelli, and others have been added to the already large list of this unusually rich locality.

"Lava, when observed as near as possible to the point from whence it issues, is, for the most part, a semifluid mass of the consistence of honey, but sometimes so liquid as to penetrate the fibre of wood. It soon cools externally, and therefore exhibits a rough unequal surface; but, as it is a bad conductor of heat, the internal mass remains liquid long after the portion exposed to the air has become solidified. That of 1822, some days after it had been emitted, raised the thermometer from 59° to 95° at a distance of 12 feet; 3 feet off, the heat greatly exceeded that of boiling water. The temperature at which it continues fluid is considerable enough to melt glass and silver, and has been found to render a mass of lead fluid in 4 minutes, when the same mass, placed on red-hot iron, required double that time to enter into fusion."—"Even stones are said to have been melted when thrown into the lava of Vesuvius and Etna. On the other hand, the temperature in some cases does not appear to have been sufficient to fuse copper; for, when bell-metal was submitted to the action of the lava of 1794, the zinc was separated, but the copper remained unaffected." (Daubeny, *On Volcanos*, p. 381.) These experiments on the heat of lava at the surface are not at all discordant with what is known of the easy fusibility of basaltic and trachytic compounds. In lava at such temperatures it might happen that fragments of granite, mica schist, &c. should escape fusion; and such are stated, on good authority, to have been found in the midst of the lava of Vesuvius, Etna, and the Ponza Isles; while limestone in a similar situation is found of that crystalline texture often observed in calcareous rocks which have undergone fusion.

The volume of melted rocks poured forth in a single short eruption of Vesuvius is considerable; far greater during some of the long-continued periods of activity of the Icelandic volcanos; enormous, if we contemplate the united effect of a whole chain of volcanos like those of South America. In 1737, the current of lava from Vesuvius which destroyed Torre del Greco, and ran into the sea, is supposed to have accumulated no less than 33,587,058 cubic feet (equal to a cube of above 322 feet by the side, or a cone of the same height and above 630 feet diameter at the base). In 1794, another current, which flowed also through the same ill-fated town, was calculated by Breislac, who saw the eruption, to equal 46,098,766 cubic feet.

Etna, which rises above 10,000 feet in height, and embraces a circumference of 180 miles, Dr. Daubeny assures us, is composed entirely of lavas, which appear to have been emitted above the surface of water, and not under pressure. "In the structure of this mountain, every thing wears alike the character of vastness. The products of the eruptions of Vesuvius may be said almost to sink into insignificance, when compared with these 'coulées,' some of which are 4 or 5 miles in breadth, 15 in length, and from 50 to 100 feet in thickness; and the change made on the coast by them is so considerable, that the natural boundaries between the sea and land seem almost to depend upon the movements of the volcano." (*On Volcanos*, p. 203.) The great current of 1669, which destroyed Catania, is estimated by Borelli to contain 93,838,950 cubic feet.

But it is in the great eruptions of Iceland, as that of Skáptaa Jokul (in 1783), that the effect of the continued energy of the subterranean fires, in ejecting matter to the surface, becomes most astonishing. The fearful eruption alluded to did not entirely cease till the end of two years: in its course the lava filled valleys 600 feet in depth; dried and took the place of lakes; accumulated in rocky gorges; spread in wide plains till they became broad burning lakes, sometimes from 12 to 15 miles wide, and 100 feet deep. The lava may be said to have taken two principal and nearly opposite directions; flowing in one 50, and in the other 40 miles, with a breadth in the former case of 15 miles, in the latter of 7. The ordinary depth of the accumulated mass was about 100 feet, but in narrow defiles it sometimes amounted to 600 feet. Mr. Lyell, from whose admirable summary of this destructive eruption the above abstract is taken, makes an ingenious comparison of this prodigious mass of *modern* pyrogenous rock with older effects of the interior heat of the globe, and illustrates its effect on the geology of England, if spread like the basaltic plateau of Antrim. Spread upon the stratified rocks of England, before their elevation from the sea bed, the lava would have occupied a vast continuous surface; and, after the rising of the rocks and their waste by watery action, the original extent might be traced. The Skápta branch of the lava might rest on the high oolitic escarpment which commands the vale of Gloucester, 100 feet in thickness, and from 10 to 15 miles broad, exceeding any which can be found in Central France. Great tabular masses might occur at intervals, capping the summit of the Cotswold hills, between Gloucester and Oxford, by Northleach, Burford, and other towns. The same rocks might recur on the summit of Cumnor and Shotover hills, and all the other oolitic eminences of that district. Plateaus 6 or 7 miles wide might have crowned the chalk of Berkshire, and masses 500 or 600 feet thick might have raised the hills of Highgate and Hampstead to rival or surpass Salisbury Craigs and Arthur's Seat. (*Principles of Geol.* book ii. ch. xii.)

To this prodigious fiery flood, there are certainly few phenomena of superior grandeur among the "wonders" of geology.

Dispersion of Ashes.

The currents of lava, though they may appear to flow with a certain regularity, are really urged by forces which continually rise to explosive energy, and dissipate parts of the liquid columns within the crater into scoriæ and ashes. This effect appears in no small degree due to a circumstance almost universally observed in volcanic excitement,—the extrication of vast volumes of aqueous vapour. To the mechanical energies which steam exerts at the base of the fiery funnel, and in the substance of the mass of lava, we may, perhaps, refer most of the phenomena attesting great expansive power. The ashes, scoriæ, and stones which are shot upwards from the mouth of the volcano, and fall in showers around, are of the same mineral composition as the solidified parts of the lava: they mostly rest on the slopes, and augment by *external layers of growth* the diameter of the volcanic mound. The white lapilli, and black ashes, remind us, in this pulverulent state, of the felspathic and augitic rocks whence they are derived; and it is probable that in this way much larger accumulations happen on and around Vesuvius, Etna, and some other volcanos, than those which are produced from flowing lava. Pompeii, Stabiæ, and Herculaneum were buried in ashes and sediments derived from ashes, to depths of 60, 80, and 100 feet; and it has been calculated that the masses ejected from Vesuvius vastly exceed the whole bulk of the mountain. (*Daubeny on Volcanos*, p. 155.)

The ashes, instead of falling round the volcanic cone, are sometimes carried for great distances by the winds. Owing to the commotion of the atmosphere during these paroxysms of the earth, rains often descend, and sweep away the falling ashes in rivers of mud ("lava d'acqua"), which flow according to the slopes of the ground, and cover up cities, and fill lakes and valleys. To this cause a part of the accumulation covering Herculaneum has been ascribed, while Pompeii was overwhelmed in dry ashes. It is easy to perceive that alluvial accumulations will from this cause spread over a large extent of country round the base of an ignivomous mountain, the arrangement of which is purely the effect of water, though the materials are exclusively the products of heat. Such *volcanic sediments* will be arranged in a consistent geological classification as *aqueous deposits;* they may contain as well as cover many organic productions, wood, shells, bones, &c., and be thus, in some cases, referred to their true geological age.

"Volcanic sandstones," as Mr. Murchison calls the marine deposits of ashes and disintegrated trap rocks, which are interlaminated among the rocks of the silurian system, may have had, in some instances, a similar origin.

Another mode of aggregation of similar ingredients is exemplified by some part of the "trass" deposit, as it is called, in the country near Andernach, where it abounds on the borders of the Eifel volcanos. Showers of ashes falling in lakes would be arranged therein exactly as other sediments from a different source, except that the areas and depths of the distributed substances must vary according to the circumstances of their admission to the water. Much of the trass in the Valley of Brohl is, however, in too irregular a state of arrangement to admit of this view. It probably was deposited rather as a mass of liquid mud, bursting from some old crater, and bearing the spoils of the surface (wood and rock fragments) with it. The wood in this trass is carbonised. The puzzolana of Naples is of similar nature to the trass, and contains shells and bones, with fragments of pumice, obsidian, and trachyte. It forms considerable hills round Naples, some of which have regular craters.

When, as in the case of Graham Island, a new volcano bursts up in the sea, and scatters ashes and scoriæ, these, falling in the sea, are variously disposed of, and may be borne by currents far from their origin. If, like the same island, the volcanic heap, after subsisting for a time, is wasted away by the waves, we can easily predict the effect on the sea bed near;—sloping strata of *volcanic sediments*, which may cover or envelop abundance of mollusca, and even fishes poisoned by mephitic gases, which frequently break forth in points not far from the centre of the eruption. Among the singularities of the eruptions of Vesuvius is the pouring forth of boiling water from the sides of the mountain (*Daubeny*, 156.). Eruptions of this nature are less rare in the New World. Humboldt mentions the singular fact, that with these aqueous eruptions pass multitudes of small fishes along with abundance of mud.

"When (on the 19th of June, 1698) the Peak of Carguairazo sunk down, more than four square leagues around were covered with clayey mud, called in the country "*lodozales*." Small fish known by the name of "prenadillas" (*Pymelodes Cyclopum*),—a species which inhabits the streams of the province of Quito,—were enveloped in the liquid ejections of Carguairazo.

These are the fish said to be thrown out by the volcano, because they live by thousands in subterranean lakes, and, at the moment of great eruptions, issue through crevices, and are carried down by the impulsion of the muddy water that descends on the declivity of the mountains. The almost extinguished volcano of Imbaburu ejected, in 1691, so great a quantity of prenadillas, that the putrid fever, which prevailed at that period, was attributed to miasmata exhaled by the fish." (*Humboldt on Rocks*, p. 455.)

Fetid mud, called "moya," burst, in enormous quantity, from the foot of the volcano of Tunguragua, in Quito, in 1797, and filled valleys and dammed the course of rivers. Sulphuric acid is mixed with the waters which flow from Purace, in Quito, and some other extinct volcanos.

Besides *ashes*, scoriæ and stones even of considerable size are thrown out by the volcanic forces, and sometimes take their course with the drifts of mud, so as to form part of the re-aggregated mass of trass, or constitute a volcanic conglomerate.

The last class of volcanic products which come to the surface are the gaseous and vaporous substances, to which much of the grandeur of the exhibition, as well as much of its general power and momentary energy, is owing. The most abundant of these is steam, which rises in white clouds over the craters of active, and from rents in extinct, volcanos. The most abundant of the gases are muriatic acid, sulphuretted hydrogen, sulphurous acid, carbonic acid, and nitrogen. (*Daubeny.*) Sublimations of particular solids occur, as boracic acid in the crater of Volcano, muriate of ammonia, muriate of soda, specular iron ore. The boracic acid cannot be sublimed by the heat of our furnaces; but Dr. Daubeny has shown by experiment, that, when heated and traversed by steam, a portion is taken up and carried with the steam.

Extinction of Volcanos.

The suppression of volcanic excitement lasts so long in some cases, that the long and quiet sleep is not to be distinguished from a real extinction of the local energy of heat. Between two eruptions in Ischia seventeen centuries elapsed. In this respect the history of Vesuvius is very instructive, especially when compared with the aspect of the long decayed volcanic mounds of the Eifel and Auvergne, whose fires were, perhaps, never beheld by man.

The cone of Vesuvius is of comparatively modern date, formed within the larger and more ancient crater of Monte Somma. The descriptions given by Latin writers seem applicable to this latter mountain, up to the great eruption of A. D. 79, which Pliny's narrative has rendered famous. Previous to that event the mountain was cultivated; its crater, perhaps, served as the encampment of Spartacus; and only obscure tradition or uncertain inference raised the conjecture that this smiling tract was based on subterranean fire. If the passage of Lucretius (vi. 748.) has any reference to Vesuvius, the only symptoms of activity of heat were sulphureous exhalations, such as might rise many centuries after the volcano had sunk to rest, such as now rise in the Solfatara, and have risen, with little difference, for 1600 years! (See *Dr. Daubeny on Volcanos*, p. 166. first edition.)

The great eruption of A. D. 79 was followed by six others, at long intervals, averaging 164 years, till 1036, when, for the first time, the flowing of lava is mentioned, the previous eruptions being of ashes and lapilli. Three eruptions are on record between 1036 and 1306. Vesuvius has never, since the first outbreak on record, been at rest for so long a period as between 1306 and 1631, between which epochs only one slight revival of action happened in 1500. Throughout this period Etna was in a state of unusual activity, as if the rival craters of Sicily and Campania were connected to the same subterranean channels. Before the eruption of 1631, the crater of Vesuvius was a pasture for cattle, its sides were covered with brushwood, in which wild boars sheltered. The old surface was all blown into the air, and seven streams of lava poured at once from the crater, committing enormous destruction. Since that time the mountain can hardly be said to have been ever tranquil, and the frequency of eruptions appears to have progressively augmented to the present time. In the seventeenth century, the intervals between the outbreaks of Vesuvius are, on an average, twenty years; in the eighteenth, five years; and since 1800, two years.

Etna has experienced, within the reach of history, sufficient variations of volcanic energy to justify the use made of its changes in the Pythagorean philosophy.

> Nec quæ sulphureis ardet fornacibus Ætna,
> Ignea semper erit; neque enim fuit ignea semper.
>
> *Ovid. Metam.* xv.

The speculations with which this opinion is accompanied, show the activity of inquiry which was excited among the people adjoining the Mediterranean volcanos.

The early eruptions of Etna are lost in the obscurity of history, and the great mass of the mountain was probably accumulated during the later tertiary periods of geology. The first recorded eruption, in 480 B. C., was followed by others, 427 and 396 B. C.; the intervals averaging 42 years. After 256 years, in which no eruptions are recorded, four more are noticed between 140 and 122 B. C.; average interval 6 years. After 66 years of rest, three other eruptions appear between 56 and 38 B. C.; average interval, 9 years. No eruption is mentioned till 40 A. D.; interval, 78 years; a pause till 251 A. D.; another, still longer, till 812 A. D.; a third to 1169 A. D.; and then, after twelve centuries of rarely interrupted quiet, the mountain became agitated, and has since continued to manifest its violence, more and more frequently, to the present century. In the twelfth and thirteenth centuries, 3 eruptions; in the fourteenth century, 2; in the fifteenth, 4; in the sixteenth, 3 of unexampled duration; in the seventeenth, 8; in the eighteenth, 14; in the nineteenth, to 1832, 6 eruptions. (See Dr. Daubeny on Volcanos, and Mr. Lyell's Principles of Geology, for details, which are here unnecessary.)

The Lipari Isles present us with yet another variation in the phases of volcanic action and rest. Stromboli is always active, but almost never violent; no cessation having ever been noticed in its operations, which are described by writers antecedent to the Christian era in terms which would be well adapted to its present appearances; while in Lipari, the only indications of volcanic action now existing are the hot springs; and the island of Volcano, in an intermediate state, still emits gaseous exhalations.

Since the first colonisation of Iceland by the Norwegians, the eruptions of the volcanos in that country have been frequent, and almost regularly distributed, through the ten centuries during which it has been known to us. Dr. Daubeny notices as the first eruption recorded, that at the end of the ninth century (894 A. D.). One also occurred in 900. The subsequent dates of eruptions are, 1000, 1004, 1029; 1104, 1113, 1157, 1158; 1245, 1262, 1294; 1300, 1311, 1332, 1340, 1359, 1374, 1390; 1416, 1436, 1475; 1510, 1554, 1580, 1587; 1619, 1622, 1625, 1636, 1660, 1693; 1717, 1720, 1724, 1728, a series of eruptions, 1748 to 1752, 1753, 1772, 1783. In 1724 occurred the first eruption of Krabla. Eruptions have subsequently occurred in 1821, 1823.*

During this period submarine eruptions happened from 1224 to 1240; in 1422; in 1563; 1783; and new islands were thrown up in 1563, 1783.

Here, therefore, we have the recorded history of four volcanic systems, which appear very unequal in their progress toward decay, as if their energy depended upon conditions differently apportioned to the several regions. Without repeating all the hypotheses in Ovid, which commence with the notion of the earth being an animal that breathes flame through many variable spiracles, we may inquire whether the fluctuation of volcanic energy in particular districts depends upon local and temporary stoppage of the channels to the surface, or upon the failure in some of the essential conditions of igneous excitement? To answer this

* The total number of recorded eruptions appears to be the following:—

From Hekla, since the year	- 1004	inclusive,	22
From Kattlagiaa Jokul	- 900	—	7
From Krabla	- 1724	—	4
In different parts of the Guldbringè Syssel	- 1000	—	3
At sea	- 1583	—	2
From the lake Grimsvatn, in	- 1716	—	1
From Eyafialla Jokul	- 1717	—	1
From Eyrefa Jokul, in	- 1720	—	1
From Skaptaa Jokul, in	- 1783	—	1
			42

Mackenzie's Travels in Iceland, p. 251.

question we must survey volcanic phenomena in a variety of other aspects.

Extinct Volcanos.

The Solfatara, near Puzzuoli, is in shape like other volcanic cones, with craters at the summit; it is formed of a trachytic rock, naturally hard and dark-coloured, but in proportion as it is exposed to the vapours given off from the "fumaroles" in the crater (the steam contains sulphuretted hydrogen and a minute proportion of muriatic acid), its texture and colour undergo a remarkable alteration. It passes through various stages of decomposition, and finally appears a white siliceous powder. Saline compounds effloresce on the surface of the rock (muriates of ammonia, &c., sulphates of alumine, lime, soda, magnesia, iron, &c.), and sulphur (not sublimed alone, but derived from sulphuretted hydrogen) lines the walls of its cavities. The ground is hollow (probably in fissures) below, and a stream of trachyte has formerly flowed from it, and formed the promontory called the Monte Olibano.

Craters in which the volcanic fires are utterly extinct are sometimes filled by water, as the Lago Agnano, and the more celebrated Lake Avernus, where no longer rise the sulphureous fumes which once procured it the formidable character of a gate of hell. (*Æneid,* vi.) They may be compared with some of the craters of the extinct Rhenish volcanos, as the Laacher See, near Andernach, which is about 2 miles in circumference, the Meerfeld, and other circular lakes or "maars" of the Eifel district. Sulphureous exhalations, which resemble those of the Solfatara, and lakes in craters like those of the Eifel, occur in Hungary and Transylvania; and the central districts of France show us, in addition, a variety of facts, to complete the view of the condition of countries where, though volcanic action, as commonly understood, is entirely extinct, the effects of subterranean heat and chemical decompositions are manifested by evolutions of particular gases, and the issue of hot springs.

Geographical Distribution of Volcanos.

Though volcanic accumulations abound in all quarters of the globe, the area which they occupy on the land is not to be compared to that of any one of the systems of stratified rocks, and is inferior to that of most of the individual formations. On a first view, volcanic mountains seem to be so many insulated points of ignition, productive of distinct mineral compounds, and subject entirely to independent local conditions. The history of eruptions, though very incomplete, is, however, sufficient to destroy this notion, by showing on the line of the Andes corresponding movements of the land, and ejections of ashes into the air, at points very far removed from each other.

Thus, a few days after the earthquake which destroyed Concepçion, on the 20th of February, 1835 several volcanos within the Cordilleras, to the north of Concepçion, though previously quiescent, were in great activity, and the island of Juan Fernandez, 360 miles to the north-east of the city, was violently shaken. The volcanos of Osorno, Aconcagua, and Coseguina (the first and last being 2700 miles apart), burst into sudden activity early on the same morning (June 20. 1835).

This connexion and sympathy of the phenomena of volcanos and earthquakes at considerable distances, is an important element for the determination of the true condition of the subterranean spaces where these phenomena are excited. The town of Riobamba, near Tunguragua, was destroyed by a tremendous earthquake on the 4th of February, 1797; and at this moment, the smoke which had been seen to issue in a thick column from the volcano of Pasto, 65 leagues north of Riobamba, suddenly ceased. Volcanic mountains appear to act as safety-valves to a boiler, and some of them relieve completely and continually the subterranean pressure, so as to free from earthquakes a considerable region round their bases. Thus, while earthquakes agitate the neighbouring islands of the Canary group, the Peak of Teyde appears to be the cause of the comparative immunity from these disasters which the island of Teneriffe enjoys.

By combining observations of this nature with considerations of the *grouping* of volcanic craters, the *direction* and extent of earthquakes, the ebullition of *hot springs*, and analogous phenomena, we arrive at the notion of *volcanic regions*, and may by this means class the active and extinct volcanos, which are scattered over the globe into a modern number of systems, convenient for description, even if the association rests on an uncertain basis.

In Europe, the purely volcanic phenomena which are from time to time manifested, appear at points referrible to one of seven centres of action. Iceland, with its Geysers and six or more active volcanos, Hecla, Skaptaa Jokul, Skaptaa Syssel, Eyafialla Jokul, and Kattlagiaa, and its formidable eruptions and coast elevations, stands almost alone; Jan Mayen, visited by Scoresby, being its only volcanic neighbour. The *Azores* form another region of considerable importance, where the rising of islands has happened within the reach of history. *Sicily*, like Iceland, has, besides the great chimney of Etna, lateral escapes of the imprisoned forces labouring below; and Sciacca, the island which rose and disappeared in 1831, is a remarkable proof of their energy. The *Lipari* Isles form another group, where Stromboli and Vulcano are still feebly active; while *Vesuvius* stands and burns amidst many older vents, long since extinguished, and *Ischia* and the *Ponza* isles bear to it the same relation that the Lipari group does to Etna.

The last centre of activity in European volcanic systems is in the Greek Archipelago, where *Santorini* has undergone many violent displacements, and some igneous exhibitions since the Christian æra.

Similarly the *extinct* volcanos of Europe may be grouped very conveniently in a few systems of connected groups. The basaltic mountains and cliffs of the Farö Isles are stated to be on many points allied to those of Staffa and Antrim, and perhaps the whole region in which igneous rocks are scattered, from the Farö Isles to Antrim, Arran, the Vales of Clyde and Forth, if not to Teesdale and Derbyshire, should be viewed as the theatre of one great and long enduring system of submarine volcanic forces.

Another great system, of more recent date, is the tripartite volcanic tract of Central France, included in the districts of Auvergne, Cantal, Velai, and Vivarais, to which we may attach some points scattered about the Cevennes mountains near Rodez, at Agde near Montpellier, and Beaulieu, near Aix en Provence.

Just before the Rhine enters the Low Countries, which conduct it to the sea, it divides hilly districts, principally of transition rocks, among which, on the left bank, is a large exhibition of ancient volcanic energy, in the numerous cones and "maars" of the Eifel country, lying east of the Ardennes. On the right bank, lower down, are the celebrated trachytic and basaltic mountains, called the Siebengebirge, which by some detached rocks of like nature, lying to the east, appear to be connected with the great basaltic masses of the Westerwald.

The Westerwald, Vogelsgebirge, and Rhöngebirge, may be taken as the principal volcanic group of Western Germany. Many insulated cones and masses of basaltic rocks about Limberg and Wetzlar, the Habichtwald near Cassel, some basaltic hills near Eisenach, Fulda, Hanau, and Frankfort, may perhaps be contemplated as parts of this ancient system.

The Kaiserstuhl mountain, near Freyburg in the Brisgau, the cone of Hohentwiel, and some small points in Würtemberg may be grouped together, though it is not known that they have really any particular geological relations.

A few detached basaltic cones appear near Egra, amidst the Fichtelgebirge. A much larger volcanic tract begins in the Mittelgebirge, and extends parallel to the Erzgebirge, and across the Elbe to near Zittau. The line of this system is continued by many detached cones across the range of the Riesengebirge into Silesia.

Volcanic appearances are mentioned near Hof, north of Olmutz.

In Hungary, as described by Beudant, the effects of extinct volcanic action are extensive and remarkable. Five distinct groups of mountains, composed wholly of trachyte, are enumerated by Beudant, who attributes to each group a separate origin. One of these groups, larger than that of the vicinity of Clermont, being 20 leagues long, and 15 broad, is situated in the porphyritic mining district of Schemnitz and Kremnitz; another, smaller, but similarly circumstanced as to the porphyry, crosses the Danube, near Grau; another, extending east and west elliptically, forms the mountains of Matra, near Eger; the fourth, a large mass, ranging north and south, for 25 or 30 leagues, from Tokai to Eperies; the fifth is the group of Vihorlet, east of the last, apparently related to the trachytic mountains of Marmarosch, in Transylvania. Most of the Hungarian volcanic rocks can be classed as varieties of trachyte, according to a method of M. Beudant; opal, opalised wood, pearl-stone, and pumice, and scorified masses, abound; and from the porphyries of earlier date, there appears to be an easy mineral gradation to some of the trachytes. The latest volcanic action is placed by Mr. Lyell in the Meiocene tertiary period. The subjacent strata are mostly of the transition æra. Another group of Hungarian volcanos adjoins the Platten See, on the north-west side.

In the eastern part of Transylvania volcanic rocks of tertiary æra occur in a range of hills covered with thick wood, extending from the hills of Kelemany, north of Remebyel, to the hill of Budoshegy, 10 or 12 miles north of Vascharhely. The principal mass of the range is trachytic conglomerate, from beneath which, at intervals, trachyte of different kinds emerges, and encloses craters at the southern end of the range. Some of these craters are, like those in the Eifel, converted to lakes. Exhalations of hot sulphureous vapours are poured out from rents in the hill of Budoshegy ; sulphureous, chalybeate, and carbonated waters rise at the foot of this mountain in many places.

In Styria, the Gleichenberg, a trachytic mountain enveloped in strata of ashes, perhaps accumulated in water, indicates considerable volcanic energy during the tertiary æra. At several other points in Styria volcanic masses appear.

The Euganean hills south of Padua constitute a very remarkable mass of volcanic deposits, consisting principally of trachytic rocks, associated with semi-vitreous masses, and at Monte Venda with basalt. The subjacent calcareous strata of "scaglia" contain many fossils of the European chalk. North of Vicenza, the variety of volcanic products is considerable, and it is thought their differences are partly related to the place which they occupy in the series of strata there occurring, between the primary slates and the scaglia. On the volcanic rocks rest calcareous and tufaceous deposits; and at particular places, especially Monte Bolca, fishes occur abundantly in slaty bituminous marls, which alternate with volcanic sediments, often containing shells, like the trass and puzzolana.

Near Viterbo (Monte Cimini), trachytic rocks abounding in leucite, associated with basalt, and beds of pumiceous tufa, covering bones of quadrupeds, are connected with tertiary marls and shells. Near Radicofani the same trachyte occurs in the Monte Amiata.

A few miles south-west of Volterra, near Monte Rotondo, and near Monte Cerboli, sulphuretted hydrogen rises abundantly from little crater-shaped openings (lagunes), and boracic acid is sublimed therewith, as well as in the crater of the island of Volcano.

Mount Albano, 12 miles from Rome, from which a current of lava is traced nearly to the city, as well as the volcanic tuff which alternates with other sediments below the soil of Rome, sufficiently prove the former activity of volcanic forces in this vicinity. Near Albano are four lakes, once probably craters. The Rocca Monfina, a mountain of great antiquity, on the road from Rome to Naples, surrounded with igneous volcanic deposits, carries on the line, of connection to the Phlegrean fields and Vesuvius.

In the Ponza Islands, Mount Vultur, the Lake Amsanctus, volcanic action, though long extinct, has left proofs of its former force and extent at points more or less connected with Vesuvius; while in the Val di Noto, the early energies of Etna are manifested among tertiary strata.

Some of the Grecian islands and shores have exhibited volcanic fire, and great elevations of land in modern times, as Santorini; and extinct volcanic action is manifested in the Solfatara of Milo, and the convulsions of Methene and Trœzena, mentioned by Strabo and Ovid.

If we compare this brief notice of the situations where active and extinct volcanos have poured eruptions on the land and in the sea, with the extent of country included by Mr. Lyell in his "Volcanic Region from the Caspian to the Azores," it will immediately appear, that, with the exception of Iceland and Jan Mayen, all the points in Europe which have produced eruptions during the reach of history, are included in that region. The whole space between the Caspian and the Azores, a distance of 1000 miles, within the parallels of 35° and 45° north latitude, has been from time immemorial agitated by earthquakes; which also extend their effects farther to the north, so as perhaps to unite the Mediterranean band of volcanic energy with the distant fires of the Icelandic group. Near to and beyond the latitude of 45° are situated many of the most conspicuous of the older volcanic systems, but the most modern lie farther to the south. The western continuation strikes the Azores. As a general conclusion, it appears that earthquakes extend the evidence of subterranean disturbance much beyond the area covered by volcanic ejections.

If, taking another view of the subject, we inquire the relation of this distribution of volcanic vents to the features of European physical geography, it immediately appears that all the *active* volcanos are situated in islands or peninsulas, or, in general, very near to the sea-side. Further, it is evident that the same law of *proximity to water* applies to the *ancient* volcanos of Auvergne, the Rhine valley, the Hungarian and Transylvanian volcanos, and the Euganean hills, &c.; for these points, now far removed from wide sheets of water, were bathed by fresh waters (Auvergne, Transylvania), or the sea (Euganean hills, &c.), at the time when they were theatres of igneous violence.

Asiatic Volcanos.

Proximity to the sea, or to large surfaces of inland waters, characterises, in like manner, the points where volcanic action is now, and has formerly been, manifested on the continent and islands of Asia. On either side of the sea of Marmora, from the Dardanelles to Constantinople, volcanic accumulations appear. Syria and Palestine, often desolated by earthquakes in early periods, abound in volcanic appearances. Near Smyrna these are extensive *, and the vicinity of the Dead Sea is volcanic. The Caucasian chain of mountains is full of volcanic accumulations; Ararat is of this character. At Bakur, on the western side of the Caspian, is the celebrated "field of fire," where excavations in the soil yield naphtha, and gas rises, which is easily inflamed. The Elburz range of mountains, on the southern side of the Caspian, presents one important volcano in action,

* Strickland, in Geol. Proceedings, 1837.

the Peak of Demavend, which is 14,000 feet above the sea.

On the Arabian side of the Red Sea, volcanic phenomena appear at Aden, Medina, Mount Sinai, and other points; the island of Zibbel Teir is said to contain an active volcano. Volcanic phenomena are mentioned at the mouth of the Persian Gulf, in the island of Ormus, and at some distance inland north of Kerman.

Beyond the limits of the Mediterranean and Caspian volcanic regions just described, Humboldt has added to the previous reasons for admitting the existence of some volcanic action in the midst of the Altai Mountains (lat. 42° to 46° N., long. E. 80° to 87°). These volcanos, which are 400 leagues from the Caspian Sea, are nevertheless situated among some considerable lakes so as to invalidate in no degree the generality of the inference drawn from the consideration of European volcanic districts.

On the eastern border of Asia is an immense sigmoidal band of intense volcanic activity, which constitutes one of the most remarkable physical features of the globe. Commencing with Barren Island, in the Bay of Bengal, the line passes south-eastward through Sumatra, where Marsden describes four existing volcanos, one of which is 12,000 feet high. Through Java the line passes nearly east and west, amidst thirty-eight large volcanic mountains, conical in figure, and rising separately from a plain to 5000, 11,000 and even 12,000 feet above the sea. In 1772 one of the largest *fell in*, so that an extent of ground 15 miles long and 6 broad, with 40 villages, and 2957 persons, were destroyed.

From Java the volcanic line continues eastward through Sumbawa, known from the formidable eruption recorded by sir Stamford Raffles, and Flores, and Timor, where the burning peak sunk in 1637, and is changed to a lake. Between Timor and Ceram, also, in one of the Banda Isles, in the northern part of Celebes, the volcanic action is manifested among the Molucca Isles. Ternate, Tidore, and Sangir, continue the line in a northerly direction to the Philippine Islands, Mindanao, Fugo, and Luçon. From Formosa, by the Loo Choo Isles to Japan, the line runs north-eastward; a course which it continued through the ten volcanos of Japan, and the nine active vents of the Kurilian islands to the burning mountains of the peninsula of Kamschatka.

The Aleutian Islands continue the line of volcanic activity (an island having been thrown up in 1795, 3000 feet in height, according to Langsdorff) to the point of Russian America called Alaschka, which is believed to be also volcanic.

American Volcanos.

Traces of powerful volcanic action, now extinct, appear about the head waters of the Columbia and Missouri rivers; and probably along more southern parts of the lofty ranges of the Rocky Mountains, yet but imperfectly known to Europe. The peninsula of California possesses, besides the lofty Mount St. Elia (17,875 feet above the sea), two other active volcanos. The line of igneous action is continued through Mexico, but not in the general direction of the high mountain range. This goes to the south-east, and it is in a line crossing it obliquely, nearly east and west, that the fire active vents of Mexico, Tuxtla, Orizaba, Popocatepetl, Jorullo, and Colima, are situated. The distance of Jorullo from the sea is 36 leagues, and that of Popocatepetl somewhat greater; and this circumstance may be thought to invalidate the seeming necessity of proximity to water as an element of volcanic excitement. But it appears not unreasonable to admit the existence here of a great transverse fissure, on whose prolongation westward are situated the volcanic (extinct) group of the Revillagigedo. Several intermediate points of extinct volcanic action connect the five active vents above noticed in Mexico.

Between Mexico and the Isthmus of Darien, in the provinces of Guatimala and Nicaragua, are no less than twenty-one active volcanos, running in the line of the great mountain chain. On the southern side of the isthmus three volcanos occur in the province of Pasto, as many in Popayan, and six of surpassing height and grandeur in Quito, viz. Cayambe, Cotopaxi, Pichincha, Antisana, l'Altar, and Tunguragua. The fire comes out from one or other of these giant cones, but, according to Humboldt, they all are parts of a single swollen mass, or immense volcanic wall, covering a surface of 600 square leagues. In Peru one active volcano is known, and there is no other between Quito and Chili, but the whole country is so remarkably subject to earthquakes, that it must be presumed the subterranean connection is continued from Quito to Chili.

In Chili, at least nineteen points of eruption are ranged in the general mountain line of the Andes, here passing southwards: Villarica, one of these, burns continually, but is seldom subject to violent excitement. One point of eruption appears to have been ascertained by captain Hall, in Tierra del Fuego. This extraordinary range of volcanos, which appears to indicate a continuous area of excitement as much as 6000 miles in length, is equally remarkable for the narrowness of its area, and its proximity and uniform parallelism to the boundary of the Pacific. According to Humboldt, all the volcanos of America have burst through older igneous products, such as basalts, trachytes, and porphyries. Granite is the basis of the trachytic masses of Mexico.

If the line of the great Mexican volcanos be prolonged to the eastward, it enters the volcanic portion of the West Indian Islands, on the west it cuts the Revillagigedos. The Gallapagos Islands are volcanic, and the same may be the case with Juan Fernandez.

In a large proportion of the West Indian Islands, volcanic appearances have been recognised; and in several the igneous action is still important. The large islands exhibit least of this. In Trinidad is a great expanse of asphaltum; in Jamaica the Black Hill is volcanic: but all the smaller islands are either of volcanic or coralligenous growth. Grenada, St. Vincent, St. Lucia, Dominica, Montserrat, Nevis, St. Christopher, St. Eustachia, are entirely volcanic; Martinique, Guadaloupe, Antigua, St. Bartholomew, St. Martin, St. Thomas, are partially volcanic, and partially calcareous. The line of these volcanic islands forms an arch convex to the eastward.

African Volcanos.

On the continent of Africa, the notices of volcanic districts are slight and incomplete. Perhaps between the Nile and the Red Sea, as Rüppell and Jomard state, volcanic action is not extinct. In Mount Atlas basaltic eruptions appear. The African islands, on the contrary, are nearly all, almost exclusively, volcanic. From the Azores, which are usually reckoned as European, the Madeira Isles continue the Atlantic system of volcanic action to the group of the Canaries. Further south, the Cape de Verde Isles, Ascension, Fernando Po, Prince's Island, St. Helena, Tristan d'Acunha, Gough's Island, are so many points of active or extinct volcanic fire. Madagascar, Bourbon, and Mauritius contain abundantly the effects of the same cause.

The circumstances observed in these various groups differ extremely. In Madeira and Porto Santo, Ascension, St. Helena, Tristan d'Acunha, the volcanic fires are extinct, and their effect has generally been to upheave stratified rocks covered by volcanic accumulations. The Canary group has, in Lanzerote, a low volcanic tract liable to burst suddenly after long intervals (from 1736 to 1834), and a vent immensely elevated for the escape from gaseous emanations and explosions, in the Peak of Teneriffe, which rises to between 11,000 and 12,000 feet, out of a concentric base of basaltic rocks, between 3000 and 4000 feet high. Von Buch believes this fact to be in favour of his general doctrine of craters of elevation, which is also supported by him upon the evidence of the form of Palma, another of these islands, which have all (according to this view) been raised from the sea, by the upheaving of submarine lava and sediments.

Australia exhibits traces of former volcanic action, in the "Dividing Range," New South Wales; and when the interior of this vast region shall have been fully explored, such may, perhaps, be found extensively.*

Indian Ocean.—A submarine volcano is noticed on the maps in lat. 7° S., long. 87° E. St. Paul's Isles, lat. 38° S., long. 77° E., are also volcanic.

Pacific Ocean.—This great expanse of water appears to be really one vast theatre of volcanic action; for almost every island raised above the water to a considerable height is more or less full of volcanic rocks, some having high and powerfully active craters; while the low islands are of coralligenous growth, and appear in forms that suggest (though Mr. Darwin offers another explanation) the belief of their being founded on volcanic mountain tops. The volcanic systems of the Pacific appear connected with the great littoral band of Asia, already described, by the line of the Banda Isles, New Guinea, New Britain, New Ireland, and other neighbouring islands. The New Hebrides, Norfolk Island, the Friendly Isles, the Society Islands, and the Sandwich Islands, and many of the detached islets which adorn the Tropical part of the Pacific, are principally of volcanic origin. The Ladrone Islands constitute a mountain chain of active volcanos. In Tahiti (Otaheite) there is an extinct crater at a height of many thousand feet; in Hawaii (Owhyhee), the enormous crater of Kirauea has been described by Mr. Ellis in his Missionary Tour. After traversing a vast surface of consolidated lava, the crater was seen at a distance, in a vast plain, sunk below a high precipice, which encircled the plain with a rugged border 15 or 16 miles round. The crater was of a crescent shape, 2 miles long (N. E. and S.W.), 1 mile broad, and 800 feet deep. Lava melted, and in violent agitation, filled this singular furnace,

* See Geol. Proceedings, Dec. 1834.

round which fifty-one conical islands rose, twenty-two of them emitting smoke and flame, and many ejecting great streams of lava, which rolled down to the fiery gulf below. This had evidently, at some time previous, been full to its edge, and was now partly emptied by lateral subterranean discharge. All Hawaii is of volcanic origin.

Geological Age of Volcanos.

Volcanos, properly so called, may perhaps have existed during all the periods of geology marked by the succession of stratified rocks; but volcanic *eruptions* on the surface of the land or *bed of the sea* are rarely known by their effects previous to the commencement of the tertiary eras. Perhaps the earliest certain exceptions to this generalisation have been found by Mr. Murchison, and Mr. De la Beche, in the silurian and Devonian rocks. In each of these instances, the evidence of volcanic eruptions such as are here meant, is found in the occurrence of layers of volcanic sediments, analogous to trass and puzzolana, in alternating succession with the ordinary deposits of water. Such facts abound on the borders of the Malvern Hills, the range of the Caradoc Hills, the Corndon Hills, and among the trappean rocks which border the granite of Dartmoor.

If the great masses of basalt, which, under the name of the whin sill, are interstratified with carboniferous limestone in the mining dales of Northumberland, were (as Mr. W. Hutton believes) spread out like lava on the bed of the sea, the occurrence of volcanic eruptions is proved from the early carboniferous eras. The mixture of porphyritic pebbles and red sandstone in Germany, on the east side of the Harz, and near Exeter, seems to render plausible the conjecture that volcanic eruptions were not unfrequent during the pœcilitic era. (See De la Beche's Manual, 2d edit. p. 365.)

The trap rocks of Skye and other islands on the west of Scotland, which are in contact with lias and other rocks of the oolitic system, can scarcely, upon good grounds, be admitted as originating in volcanic eruptions: they are mostly unerupted lavas.

In tertiary periods of geology, traces of eruptions became frequent. According to Lyell, the oldest volcanic rocks of the Limagne d'Auvergne belong to the eocene tertiary period, being associated with freshwater strata at Pont du Château near Clermont, and in the Puy de Marmont near Veyres. None of the volcanic eruptions of Central France had, however, commenced when the older subdivisions of the freshwater groups originated.

The newer portions of the Mont Dor and Plomb du Cantal are stated by this author to be of meiocene date, as well as some cones which stretch from Auvergne, through Velay, into the Vivarais, where they are seen in the basin of the Ardêche. Finally, Etna, which commenced its operations during the newer pleiocene era, has continued them down to recent times with undiminished energy.

Had we included in this review the cases of *unerupted lavas* (basaltic and porphyritic dykes and interposed masses), there would have been an unbroken series of igneous products, cooled in subterranean, submarine, or subaërial situations, from the earliest primary eras down to the present day; and from the whole we should clearly see how very probable, or rather certain, it is, that granitic and other plutonic, as well as volcanic, rocks are not so much the products of the particular times as of the particular circumstances in which igneous action has been manifested.

Volcanic Eruption Forces.— Earthquakes.

The degree of mechanical pressure under which lava is effused, and ashes are ejected, from volcanic vents, is of importance in the theory of their action; and when combined with indications of the same kind in earthquakes, enters among the data requisite for comparing the agencies of subterranean movements in ancient and modern periods.

Ejections of Ashes and Stones. — The *distance* to which these are transported after leaving the volcano, is a useful indication of the quantity ejected, and thereby of the general power of an eruption, but not a measure of its momentary violence. During the eruption of Vesuvius in 472—473, the ashes thrown out were transported by the winds even to Africa, Syria, and Egypt, and fell in Constantinople. In 1631, ships were covered with ashes 20 leagues from Vesuvius. In 1812, the eruption of the Souffrier Mountain, in St. Vincent's, gave forth ashes which were carried by the winds to Barbadoes. During the terrific eruption of Tomboro, in Sumbawa (1815), clouds of ashes obscured the sun, and fell, inches deep, on the streets and houses in Java, at a distance of 300 miles.

The *intensity* of the volcanic force can be better appreciated by the magnitude of the stones ejected from the crater, and the height and distances to which they are thrown, than by any other criterion. It appears that stones 8 lb. in weight were thrown from Vesuvius to Pompeii, a distance of 6 miles; and stones were observed by sir W. Hamilton to be thrown so high above the mountain top, that they occupied 11″ in falling, which gives a height of 2000 feet, and an initial velocity of above 350 feet in a second. In 1798, during a violent eruption in Teneriffe, the mountain Chahorra threw out stones to such a height that from 12 to 15 seconds were reckoned during their descent. The height was consequently from 2500 to 3600 feet, and the initial velocity from 380 to 480 feet per second. The pressure of a whole column of lava, which should overflow the crater of Teneriffe, would, according to Daubuisson, be equal to 1000 atmospheres, and might eject lava, *at the base*, with a velocity of nearly 850 feet per second. These forces are much inferior to those with which cannon balls are projected. The intermitting character of these "fits" of volcanic violence is favourable to the notion of their principally depending on the sudden evolution of the force of steam, with whose operation in this way we have been familiarised by the steam gun of Mr. Perkins.

The formation of *New Mountains* is another phenomenon which strongly indicates the importance of volcanic operations in changing the aspect of the globe. The cases are numerous. In 1538, in or near the site of the ancient Lucrine Lake, in the Bay of Baiæ, the Monte Nuovo was thrown up, in 48 hours, to a height of 440 feet, with a circumference of 8000 feet, from a crater of eruption, which has been measured to the depth of 418 feet in the middle. In 1669, the Monte Rossi was thrown up on the slope of Etna, 450 feet in height, and 2 miles in circumference; this was accomplished in three or four months. The formation of Jorullo, in 1759, to a height of 1695 feet, is one of the most remarkable effects of this kind. (See page 204.)

The *New Islands* which have been raised from the sea by volcanic explosion or movement of the sea bed, furnish additional facts; and probably a large proportion of these striking phenomena is unrecorded, and many more must pass away without notice, notwithstanding the increased facilities which extended commerce and general scientific education have afforded for recording them in future.

The changes which have occurred in and about the Island of Santorini, from an epoch 237 years before Christ, to almost the present year, are remarkable, the general effect being an augmentation of the land. The new island of Sciacca, which appeared in July, 1831, and disappeared in the course of the following winter, is one of the most interesting events of this kind known in modern times. It appears that a line of earthquakes may be traced from Corfu, by Calabria, to Etna, which, in its extension westward, nearly strikes the volcanic island of Pantellaria. Between Pantellaria and Sicily, on this line, submarine movements were noticed in June, 1831: soon afterwards the signs of an eruption were seen by Neapolitan fishermen; and on the 18th of July, a British man of war passing near the spot, white columns were seen in the sea, rising from a dark hillock, which threw up stones and ashes. It was then judged by captain Swinburne to be 70 or 80 yards in diameter, and about 20 feet high. In August it had grown to a circumference of 3240 feet, its height being 107 feet; and in the middle was a crater 780 feet in circumference; the columns of ashes rose to a height of 3000 or 4000 feet. The evolution of gases was inconsiderable. When examined, the mass of the island was found to be a dark vesicular lava, with a few fragments of limestone, and other non-volcanic rocks. On the 28th of September, according to Prevost, the circumference of the island was 2300 feet, and the height from 100 to 230 feet. In the winter of 1831-2, its loose and perishable fabric had yielded to the action of the waves, and disappeared from the surface. It is now a dangerous shoal, shelving gradually to the deep sea bed (100 fathoms), out of which it originally sprung; on the neighbouring parts of the sea bed, probably, a considerable deposit of volcanic sediment is spread. Such is the history of the vanished island of Sciacca.

In the Azores, in 1628, an island rose from 160 fathoms water, in 15 days, to a height of 360 feet above the sea; Mr. De la Beche has found in the MS. of the Royal Society, a notice of another island, which had been thrown up in 1690, but soon afterwards, like Sciacca, was dissolved and sunk again in the sea.

In 1811, off St. Michael's, in the same group of islands, a volcano was observed to be active in the sea, on the 13th of June. On the 17th it shot up black columns of cinders to the height of 700 or 800 feet above the sea, and at other times clouds of vapour; the eruptions being accompanied by great noises and vivid lightnings. On the 4th of July, the island which was formed was 1 mile in circumference, almost circular, and about 300 feet high; the crater discharged hot water. This island, to which the name of Sabrina was given, disappeared like Sciacca.

In 1783, a new island rose in the sea near Reykiavich, in connection with the Icelandic volcanic system: it was 1 mile in circumference, but soon disappeared like so many of these already mentioned.

The ejections from the summits and sides of volcanos go to enlarge the mean diameter of the globe, whether they be heaped on the land or laid on the bed of the sea. The amount of this augmentation of diameter has never been estimated (we believe), nor would the estimate, perhaps, be worth the slight trouble of the calculation, were it not useful to moderate the false impressions which a contemplation of the violence of ignivomous mountains occasions. If we suppose the volcanic lines and groups known on the globe to be collected in one line, it would not equal a great circle of the sphere. If we take as the breadth of this volcanic band a surface of 10 miles, we shall much exceed the average. To assume that half the mass of active or extinct volcanic mountains above the sea is the product of subaerial or submarine eruptions is an ample allowance. Finally, if the figure of the mixed volcanic and rocky mass be taken as a series of cones, 2 miles in height, which is far above the truth, the mean volume of igneous products resulting from the calculation is $\frac{24000 \times 10 \times 2}{3 \times 2}$ miles $=$ 80,000 cubic miles; which, if spread over all the globe equally, would augment its diameter about $2\frac{1}{4}$ feet. Now, as all the conditions have been taken in a sense the most favourable for the magnitude of the result, we see how feeble, after all, is the change of the general conditions of the globe, produced by the agents of violence put in action during volcanic excitement.

The cavities left within the globe, by the ejection of this mass of matter, are probably so circumstanced by the overarching of their roofs, that they may resist for a long time the tendency of the superincumbent weights to fall in; but there is a limit to this resistance. When the superficial accumulations are of vast height and great lateral extent, as in some of the mighty volcanos of America, the internal heat rises upward, in the substance of the mountain, so as to re-absorb the base of the cone, and weaken its strength. From this cause, perhaps, it happens that sometimes volcanic mountains *fall into* the cavity below them, and are swallowed up. Thus the great mountain mass of Papandayang, in Java, fell into the greater cavity out of which it had been raised; and l'Altar, in Quito, lost its commanding summit.

The subterranean connection of even distant volcanic mountains, and the reciprocity of action between what appear on the surface to be distinct volcanic groups, justify the belief that the sources from whence the eruptions are supplied with mineral matter spread widely around the volcanic vents; an inference still further strengthened by the extension of earthquakes beyond the regions of burning mountains. It follows that *movements of subsidence,* which are occasionally witnessed in really volcanic districts, may, and indeed must, happen sometimes in other situations, where *lines or surfaces of weakness* exist, in the earth's crust, Such depressions may be either gradual or sudden, according to the circumstances which determine the points and degrees of relative weakness in the earth's crust, and from all the considerations it is easy to perceive that the real change of the earth's diameter, by the explosive action of volcanos, is very small, and much counterbalanced, in all periods, by the contrary effects of subsidence; and that in the progress of volcanic operations a limit must at last be reached, when the two opposite effects of the same cause must be exactly balanced, though not necessarily in the *same physical regions.* The general result, then, is an augmentation of the heights by volcanic energy, and a deepening of the depths by the consequent subsidence.

Far from the centres of volcanic excitement, the compensating depressions of the earth's crust would probably be gradual and almost insensible: in such situations there may also occur equally gradual and almost imperceptible elevations of particular tracts of land, because if there be a *real sinking* over lines and surfaces of weakness, there will be *relatively* a *rising* over points having the contrary properties. There may also be a *real rising* of such parts, with a *relative sinking* of others, if the arrangement of the rocks is such as to give maxima of strength in opposite directions. The ordinary and well-known forms of anticlinal and synclinal axes are examples of such figures; for an upward general pressure, such as accompanies volcanic violence, may more easily extend and raise an anticlinal mass, and a subsequent general collapse would act with more force on the synclinal surfaces of stratification. Other causes concur to augment these effects, which are certainly exemplified in observed phenomena of the relative levels of land and sea.

In conformity with this reasoning, we find, on the testimony of all writers who have examined the history of earthquakes, that they are by far most abundant and most violent, in countries which surround or lie between volcanic districts. Before and during volcanic excitements, earthquakes abound, so as evidently to make part of the same phenomenon; and, even under countries where volcanic fires are dormant or extinct, these convulsions of the solid framework of the earth are more powerful than in remoter districts. It is in volcanic countries that proofs have been found of the real displacement and positive elevation of land, on particular days, and during particular earthquakes; while at points far remote from Vesuvius and Hecla, the land is slowly rising in Scandinavia, perhaps slowly sinking in Greenland, perhaps alternately elevated and depressed on some parts of the shores of Britain.

Examples of permanent displacements of land, arising from *convulsive* movements near the seats of igneous activity, are furnished by the Calabrian earthquakes of

1783, the Lisbon earthquake of 1755, the Chilian earthquakes of 1822 and 1835. In 1822, according to Mrs. Graham, the Chilian coast was agitated by a movement which extended in length 900, 1000, or perhaps 1200 miles (including Copiapo and Valdivia), and raised the whole line of coast for a distance of 100 miles; at Valparaiso 3 feet; at Quintero 4 feet; the greatest movement being about 15 miles N. E. of Valparaiso: the beds of oysters and other shells were raised clear to the surface. The whole region between the Andes and a line far out in the sea is supposed to have been permanently raised, 2, 3, or more feet (in the interior the elevation is said to have reached even 7 feet). The area under which, ashore, the earthquake extended, is estimated at 100,000 square miles.* If, as Mr. Lyell supposes, the whole of this vast area was raised, and the elevation be taken at 1 foot on the average, the whole augmentation of the earth's diameter caused by it will be $\frac{1}{4000}$th part of that which we attribute to the whole mass of visible volcanic accumulations on the surface. It is unnecessary to re-open the discussion of the accuracy of the data above assumed, because in 1835 similar phenomena happened on another part of the same coast.

This second great disaster on the Chilian coast has been described by Mr. Caldcleugh, from his own and other observations, with much care. It was heralded by the landward flight of immense flocks of sea-birds (the same thing occurred previous to the shock of 1822), and by the remarkable activity of the volcanos of the Andes. An enormous wave, rising 28 feet in height, destroyed Talcahuano, and was followed by a greater. Columns of smoke rose in the sea, followed by whirlpools. In the Bay of Concepçion the strata of clay slate were elevated about 3 or 4 feet. At San Vicente,

* Journal of Science, vol. xvii. p. 46. It is not here asserted that 100,000 square miles were "permanently altered in level." It is stated that the "principal force was exerted in a circle of 50 miles diameter, having its centre N. E. of Valparaiso," and again the force diminished in proportion to the distance from Valparaiso.

a port a little south of Talcahuano, the land rose about 1 foot and a half. In the small island of Santa Maria, the rise was estimated by Captain Fitzroy at 8, 9, and 10 feet! At Nuevo Bilbao, 70 leagues north of Concepçion, the earthquake was violent, but there is no permanent elevation of the land. Throughout the entire provinces of Canquenes and Concepçion, the crust of the earth has been rent and shattered in every direction. An hundred miles from the coast vessels experienced the shock. The island of Juan Fernandez was included in the area of the submarine disturbance, which below the land reached northward as far as Coquimbo.

It is remarkable that Acosta speaks of very similar effects of waves and violent movements in the same range of coast, in the 16th century; and other instances have been collected by Mr. Woodbine Parish.

Though, for reasons before stated, we cannot expect to find cases of sudden depression in volcanic regions so frequent or extensive as those of elevation, enough is known to assure us that in and beyond these regions, earthquakes have very often caused subsidence of land. We read, that in the year 541 Pompeiopolis was half swallowed up in an earthquake; that in 867 Mount Acraus fell into the sea; that in 1112, the city of Liege was flooded by the Meuse, and that of Rotemburg on the Neckar was ruined. In 1186, a city on the Adriatic shore is described as sinking into the sea; in 1596 the sea covered many towns in Japan; in 1638 St. Euphemia became a lake; and in 1692 Port Royal is commonly believed to have sunk. In 1755, the great earthquake caused a new quay at Lisbon to subside, and its place was occupied by water 100 fathoms deep, and other similar cases of engulphment occurred on the Portuguese and African shores. In 1819, extensive subsidence occurred with the submersion of a town and large tracts of country, at the mouth of the Indus, and in the same vicinity rose a compensating elevation, called "the Ullah Bund."

That earthquakes are experienced over regions far from volcanic mountains is easily ascertained by consulting the imperfect records which have been preserved of these phenomena in Europe. For it thus appears that in Norway, Scotland, England, Belgium, and many parts of Germany and France, considerable earthquakes have occurred, not only at a distance from European volcanos, but also without any definite relation of time to the eruptions of the Icelandic or Mediterranean volcanos. In a long catalogue which we have drawn up for the purpose of comparing the dates of earthquakes in Great Britain with the recorded eruptions of those volcanos, &c., the last 1000 years, we have found scarcely any accordance.

The movement of the ground during an earthquake is described variously, — as a vibration, a rolling, an undulation, a shock; but it is to be regretted that these terms do not always convey a definite and exact notion of the kind of disturbance which really takes place. Some observers speak only of *vertical* movements, such as were experienced during the Lisbon earthquake by a vessel far west in the Atlantic; others mention *horizontal* movements, as during the Chilian earthquake of 1835. In general, there is an impression that the movement of the ground travels in one certain direction, like a wave upon water; this direction was remarked to be different in the northern and southern portions of country shaken in Chili in 1822. There is sometimes one shock, in other cases several, seldom many successive impulses from below. The most violent movements appear to have been experienced on the sea-side, and in the sea itself, which, retiring and returning with mighty waves, 10, 20, or even 60 feet high (in the Lisbon earthquakes of 1755), produce incalculable mischief and destruction of life and property.

Were the globe a solid mass at great distances from the seat of the original disturbance, these effects could not happen, unless, as Mr. Mallet has shown, a wave of elastic compression were generated, which should travel like a great wave of translation in water, with velocities corresponding to the elasticity of the rocks, so as to reach Lisbon, Loch Lomond, Italy, and the West Indies. Rocks, we know, are elastic in their parts, but very imperfectly so in their mass, owing to the numerous divisions which intersect them. Earthquakes cannot be compared to the vibrations of a string, or the pulsations of sound, gradually falling to rest; the motion observed is more similar to the undulation of a flexible lamina over an agitated liquid; — as when a long cloth is shaken in a particular manner, so that a wave of air travels below its parts successively to the end.

Mitchell, to whom physical geology is largely indebted, was the first to explain earthquakes by wave motion, and he employs for the purpose the mechanism of a fluid thrown into undulation, or vapour operating by expansion beneath or between the strata.* He assigns 1750 feet per second for the velocity of the Lisbon earthquake. Professors H. D. and W. B. Rogers, following in the same track, make the phenomena of earthquakes depend on undulations propagated in molten rock below the solid crust, trace the path of some of these phenomena, and give measures of the rate of progress of the wave: viz., 27 to 30 miles per minute, or about twice as fast as the wave of sound in air. They find for the velocity of sea waves generated by the earthquake shock, 3½ and 5 miles an hour.† They find the area agitated by earthquakes at any one epoch to be very long and narrow, corresponding to the great wave of translation, and trace the synchronous lines of movement for several hundred miles in length.

Mr. Mallet, in a paper communicated to the Royal Irish Academy‡, followed by a Report to the British Association, has entered fully on the dynamics of earthquakes, and on the history of these phenomena; and has performed some capital experiments on the rate of movement of earth waves in incoherent sand, and in granite of perhaps the average degree of consolidation.§

* Phil. Trans. 1760.
† Reports of the British Association, 1843. ‡ Ibid. 1846.
§ Communicated to the British Association in 1851.

From the point where the earthquake originates, two sets of waves proceed in the solid crust of the earth, viz., the *wave of elastic compression*, propagated in every direction with a velocity proportioned to the elasticity and density of the parts of the earth-crust in its path. In different sorts of rock the velocity will not be the same: it will be greatest in the solid, and least in the loose aggregations of matter. Another set of waves is that of *sound*. And, if the origin of the earthquake be under the sea, a *water wave* of translation will be generated in the sea, of much less velocity than that in the earth. Sound waves will be communicated to the water and to the air; but of these we need not say much. If the earthquake originate under the land, and be propagated under the sea, it will reach the extreme border of the sea, and raise the shore so as to force the water to appear to retire, and afterwards to return and flow higher than before, a phenomenon distinctly observed. Supposing the first shock to have happened under the sea, and all the waves to be noticed on the extreme edge of the water, we should have,

1. The earth waves of shock and sound together, or nearly so.
2. The forced sea wave lost upon the beach.
3. The sound wave through the sea.
4. Sound waves (possibly) through the air.
5. The great water-wave, which has been found so destructive.*

According to Mr. Mallet, the velocities to be expected in the sound-wave would be 4700 feet per second in water, 1140 feet in air; and, judging from the elasticity, in lias 3640; in coal measure sandstones 5248; in oolite 5723; in primary limestone 6696; in carboniferous limestone 7075; and in hard slate 12,757; and in granite and igneous rocks still higher rates. Perhaps the speed of the great earth-wave may be nearly the same; but the masses of rock in the earth are so much interrupted by joints, by unequal condensation, varying

* Mallet in Brit. Assoc. Reports for 1850.

inclination, and other circumstances, that as appears in the case of the Lisbon earthquake, in Mitchell's, Rogers's, and Humboldt's estimates, ($\frac{1}{3}$ to $\frac{1}{2}$ a mile in a second,) the real velocity is much less. Mr. Mallet has ascertained it in the case of sand and granite to be even less than the above instances, and his experiments were so arranged in the sand at Killiney and the granite of Dalkey, as to give very accurate results. For his beautiful process the reader must be referred to the Brit. Assoc. vol. for 1852.

It appears very desirable, for the completion of this theory of earthquakes, to carry out the seismometrical observations recommended by the British Association, especially at the great public observatories.

Mr. Hopkins in treating this subject mathematically, has shown how, by proper observations of this kind, the local origin of the earthquake can be determined in depth, as well as in geographical position.*

The force of an earthquake shock diminishing at points removed from its origin as the square of the distance increases, we see how great must have been the shock in the case of the Guadaloupe earthquake (1843), when, as Rogers has shown, an area not less than 2300 geographical miles in length by 770 in breadth was agitated. According to the observations made on this occasion, the shock was simultaneous in lines nearly north and south, and felt moving in opposite directions from a curved central axis, at the rate of 27 miles in a minute. This seems to indicate a linear subterranean fracture of great length — a fault geologically speaking — such as might occur over a cavity left by the withdrawal of a fluid support to the earth's crust.

By a mathematical investigation of this subject, founded on the phenomena of precession and nutation which arise from the action of the sun and moon on the unspherical mass of the earth, Mr. Hopkins has shown that whether the earth be partially fluid or wholly solid within, there would be no material difference in the

* Brit. Assoc. Reports, 1847.

precession and nutation, provided the ellipticities of the interior and exterior surface of the supposed solid crust were equal, and the density of the crust and fluid equal and uniform. But if these limitations were not observed; if the solid shell and interior fluid were heterogeneous, and the ellipticities of the interior and exterior surface of the crust different, then the amount of the precession and nutation would depend on the difference between the ellipticities of the interior and exterior surface of the crust, and on its thickness: or on this latter quantity alone, if the solidity of the shell resulted from refrigeration. And the result of the whole inquiry appears to be, that the thickness of the solid crust cannot be less than $\frac{1}{4}$th or $\frac{1}{5}$th of the radius of its external surface.* This conclusion is probably decisive against any *universal* ocean of molten rock below us, at depths accessible to the disturbing agents which generate earthquakes and volcanos: but it seems not to preclude the admission of *limited* fluid masses, at various and far smaller depths than 1000 or 800 miles. In harmony with this view is the opinion of Mr. C. Darwin, who, from considering the circumstances which accompany volcanos and earthquakes in the Cordilleras of the Andes, proposes, as a fundamental point of reasoning, the recognition of the existence of a vast internal sea of melted rock below a large part of South America.†

This conclusion appears liable to so little objection; it is, besides, so perfectly in harmony with the fact historically proved of the perpetual readiness of volcanos for action, and with the geological inference of the perhaps unlimited extent below our feet of rocks once fused; that we shall venture to adopt it as a datum sufficiently established, and applicable to the whole series of volcanic phenomena, in every country, and during all past periods of time.

But this ocean of melted rock may sleep, and does remain at rest, beneath enormous areas, for centuries, or much longer periods, till some particular *causes* concur to "change (as Mr. Darwin expresses it) the form of

* Phil. Trans. 1839, 1840, 1842. † Geol. Proceedings, 1838.

the fluid surface," and develop extraordinary chemical energy and fearful mechanical violence. What are these causes? and what is the condition of the subjacent fluid masses whose repose they disturb?

Hypotheses of Volcanic Action.

To answer the questions just proposed, is the object of a just theory of volcanic action. The conditions already established, of the great extent of the phenomena, the appearance of volcanic fires in every kind of rock, and the continuity of such operations not only through historical but through earlier geological periods, negative completely the trifling notion of any particular combustible substances, or decomposable chemical compounds, being sufficient to maintain such long-enduring and powerful operations of heat. We must adopt larger and yet more definite views on the subject. No supposition will be of the smallest value, which provides an agency inferior to the area, unequal to the mechanical violence, or inconsistent with the chemical characters of volcanic excitement.

Accordingly, only two hypotheses have been deemed worthy of attention in the modern consideration of this subject. Humboldt, Cordier, and other eminent geologists, reviving the opinion of Leibnitz, look upon volcanic action as the necessary result of the influence exerted by the heated interior upon the cooled exterior masses of the globe. If the earth be now generally hot within, it must formerly have been hotter; in the process of cooling, the exterior solidified part and the interior fluid parts contract unequally, a general pressure and tension result, and the crust breaks locally to restore the equilibrium. Hence earthquakes, and fissures, on some of which volcanic vents are established, which serve more or less to relieve the subterranean pressure, as earthquakes also do. If, in addition to this general view, we suppose the admission of water through fissures to particular parts of the "ocean of molten rock," it is easy to see that the observed mechanical phenomena of volcanos and earthquakes will result as the effect of a local excitement superadded to a general operation. Such is an outline of the explanation offered by the hypothesis of a general heat pervading the interior of the globe.

Mr. Darwin, in his summary of the phenomena attending earthquakes on the coast of Chili, in 1835, regards, very justly, the submarine outbursts, the renewed volcanic activity, and the permanent elevation of the land, as forming parts of one great action, and being effects of one great cause, modified only by local circumstances; and that, therefore, "no theory of the cause of volcanos, which is not applicable to continental elevations, can be considered as well established." This appears a just inference. He is further of opinion that the following conclusions may be drawn from the phenomena of earthquakes.

1st. That the primary shock of an earthquake is caused by a violent rending of the strata, which, on the coast of Chili and Peru, seems generally to occur at the bottom of the neighbouring sea.

2d. That this is followed by many minor fractures, which, though extending upwards, do not, except in submarine volcanos, actually reach the surface.

3d. That the area thus fissured extends parallel, or approximately parallel, to the neighbouring coast mountains.

Lastly. That the earthquake relieves the subterranean force *precisely in the same manner as an eruption through an ordinary volcano.*

Now every thing here said may be adopted, without hesitation, into the general speculation of Humboldt, of which, in fact, these inferences from observation are strongly illustrative.

Another view, which is strongly supported, is usually considered by its defenders as "the chemical hypothesis" of volcanic action. It presented itself both to Davy and Gay-Lussac, as a natural consequence of the discovery of the metallic and metalloid bases of the earths and alkalis; and though the former eminent philosopher abandoned his speculation, it has found able support in Dr. Daubeny. The account given by Daubuisson will clearly exhibit the opinion of Gay-Lussac. "If we admit, what is in fact almost certain, that water enters in great quantity to the foci of volcanos, and there comes in contact with the metalloid bases of the earths and alkalis, and some chlorides (especially the chloride of sodium), the following effects will happen:— One part of the liquid will be quickly decomposed; the metals and the chlorides will seize oxygen, and be thereby converted to silica, alumina, lime, magnesia, soda, &c.—substances which predominate in lavas; the hydrogen will be liberated in the state of gas, or in combination with chlorine will form hydrochloric acid, which is known to be very often present in the vaporous exhalations of volcanos."* The heat generated by the primary chemical action (oxygenation) and the energetic action of steam, to which part of the water is converted, are thought sufficient to account for the mechanical phenomena of volcanos.

Dr. Daubeny has given to this speculation a character of greater completeness, by an examination of the actual products of volcanos, for comparison with a regular deduction of chemical phenomena from the fundamental postulates of Gay-Lussac and Davy.

If, at a depth of 3 or 4 miles, the nucleus of the earth consists of the metalloid bases of the earths and alkalis, with iron and other metals, partially combined with sulphur,—the new oxygenation to which, under ordinary conditions, they would be subject, may be productive of no other phenomena than a moderate rise of temperature in the neighbouring rocks or in thermal springs.

But *with access of water*, and especially sea water, the effects of the heat generated will become more formidable. Oxygenation on an extensive scale; evolution

* Traité de Géologie, tom. i. p. 206.; and Ann. de Chimie, tom. xxii.

of a large volume of hydrogen, again to combine with oxygen (supposing atmospheric air present), or with sulphur, *at a high temperature.* In the former case, nitrogen gas will be liberated, which may rise uncombined, or may unite with hydrogen to form ammonia; and this will be neutralised by free muriatic acid, and produce sal ammoniac.

The hydrogen not thus disposed of may combine with sulphur to form sulphuretted hydrogen gas; but this may be again decomposed by rising and meeting with oxygen; as long, therefore, as oxygen abounds, there will be evolution of water and sulphurous acid; afterwards sulphuretted hydrogen will prevail toward the end of the eruption. As long as heat remains in the lava, the combustion of sulphur, and the decomposition of the sulphurous acid by sulphuretted hydrogen, would regenerate water, to maintain, by combination with metals and metalloids, a continuance of similar though feebler actions.

There is not, we believe, any attempt on record to deduce all the *chemical* phenomena of volcanos from the hypothesis of general heat below the surface of the earth: we must therefore, at present, suppose this is difficult, except upon the admission of that powerful absorption of oxygen from water, which the "chemical" hypothesis provides. Granting, then, the truth of these opinions as to the origin of the substances ejected from volcanos, do they involve the rejection of the hypothesis of a pervading high temperature below the surface of our planet? Surely not.

For what account does the peculiar series of gaseous and earthy ejections from a volcano give of the *origin* of the volcanic action? What opens the fissure and gives passage for the water to the base of volcanic mountains? The whole crust of the globe, stratified and unstratified, is a mass of metallic oxidation; how can there yet remain, at so many points, access for water through this oxidated crust, to the unseen primitive nucleus? How happens it, that really volcanic effusions are so limited and so few among the older strata, which were formed when the stratified crust of the globe was thinner, and (by this hypothesis) the unsaturated metalloid bases were more plentiful near the surface?

It appears to us very clear, that the union of the two speculations here brought into comparison is not only practicable, but reasonable, and even necessary. A general cause of *change of form* of the earth's surface and interior parts is supplied by the doctrine of a change of interior heat; abundant admission for water is afforded by the *fractures* necessary (upon this view) to adjust the balance of pressures; and the chemical products can only be properly understood by a suitable hypothesis of chemical action. The interior mass of the globe may yet retain the uncombined bases of earths and alkalis; but the *chemical* products resulting from admission of oxygen to these are not at all the less intelligible, if we suppose the whole mass of the interior to have those general conditions of heat which appear to suit the *mechanical* disturbances of the land and sea. On this point, however, further researches on collateral phenomena may be prosecuted with advantage, and to these we now proceed.

Thermal Springs.

In general, the springs which issue from the earth derive their origin from rain which has descended through fissures of the rocks (especially calcareous rocks), and, in consequence of meeting with natural impediments to further descent,—as beds of clay, dykes, mineral veins, faults,—collects in the rocky reservoirs, rises to the surface, and issues at the point to which access is easiest, whether it be the lowest point of the vicinity or not. The rains which supply such springs descend irregularly; yet, if the subterranean reservoirs be considerable, the discharge is nearly constant in all parts of one year, and in many succeeding years. To each of such springs usually one particular chemical quality is imparted by the rocks through which the water passes; and one particular average temperature belongs to each, generally identical with that of the ground through which it passes.

This temperature seldom differs much from the mean annual heat of the locality, and, unless the stream be subject to variation of quantity, hardly varies with seasons or years.

It has, however, been found that the small differences which appear between the mean temperature of the air and of springs at particular localities, are of a somewhat regular character, and bear a general if not a precise relation to latitude. It was found, for instance, by Dalton (1793), that the springs at Kendal gave a somewhat higher range of temperature than the air: the same observation has been made at Berlin, Paris, and other places in the North Temperate Zone; but in the equatorial region the contrary appears to be the fact. The tables of Kupffer (which may be consulted in De la Beche's Manual of Geology), constructed from observations of Humboldt, Von Buch, Cordier, Wahlenberg, Kupffer, &c., appear to give as much as from 1° to 5° superiority of air temperature above that of the ground; while in latitude 54° to 60°, in Russia, the springs were warmer than the air by 5° or 6°.—This fact appears to show clearly that the temperature of the earth and of springs is influenced by *some general cause* independent of solar heat.

Besides the class of ordinary springs, which may thus differ by small amounts from the temperature of the air, there are "thermal springs" which often deserve the name commonly assigned to them of "hot springs," and sometimes approach even the boiling point. These are usually found to be almost, or even absolutely, constant in their discharge, uniform in their temperature, and unvarying in their chemical composition. Some of the sources frequented by the luxurious nations of antiquity still retain their efficacy,—in Greece, in Belgium, and at Bath; and the inquiry into the cause of this continued heat becomes the more important when we consider the great geographical area over which hot springs are scattered, the singularity of their association with cold and mineral waters, which is often noticed, the variety of their contents, and the geological circumstances which accompany their efflux.

It is unnecessary to dwell at any length on the question, how far any peculiar chemical quality is characteristic of hot waters, so as to offer a satisfactory explanation of their warmth from chemical action. There is no such peculiarity. Thermal waters are found to be, on the average, neither more nor less pure than springs of common temperature; they exhibit, in fact, the same scale and variations of chemical constitution as common waters. The *chemical quality* of hot waters, offers no *explanation* of their heat, though, combined with other considerations, it may help to guide to a right view of the manner in which that heat has been acquired.

There is no one product of thermal springs, constantly found in them, which never occurs in cold waters; but it appears from Dr. Daubeny's important researches, that nitrogen gas is very common in hot springs, and perhaps very rare in cold waters. This circumstance appears to him of great importance in the argument whereby he connects the origin of hot springs with volcanic action. In Dr. Daubeny's admirable Essay on Mineral and Thermal Waters *, the catalogue of thermal waters exhibits the prevalence of nitrogen, among the gases evolved, in a striking degree; carbonic acid is also plentiful, and, in particular districts (Nassau), predominant. As examples, we may select the notices of the warm springs of the British islands, and of those which adjoin the Ardennes and Nassau mountains, — in both instances only obscurely dependent on volcanic formations; the Pyrenean and other springs may also be noticed.

* Reports of British Association, 1836.

Warm Springs of the British Islands, yielding Nitrogen, &c.

1. *Bath.* — The King's Bath spring rises through lias*, at a temperature of 66° above that of the neighbourhood; contains saline ingredients, 15 grains in a pint (muriate of lime and magnesia); evolves 96·5 per cent. nitrogen, 3·5 oxygen, and some carbonic acid.
2. *Bristol.* — The Hot Well rises in carboniferous limestone, at a temperature of 25° above that of the place; contains saline ingredients, 6 grains in a pint (sulphate of soda and muriate of lime); evolves 92 per cent. nitrogen, and 8 oxygen.
3. *Buxton, Derbyshire.* — St. Anne's Well rises in carboniferous limestone, at a temperature of 33° above the vicinity; contains saline ingredients, only 1·8 grains in a pint (muriates of magnesia and soda); evolves nitrogen only.
4. *Bakewell, Derbyshire.* — The Bath spring rises in carboniferous limestone, at a temperature of 13° above the vicinity; contains saline ingredients, 3½ grains in a pint (sulphate of lime and muriate of soda); evolves nitrogen only.
5. *Stony Middleton, Derbyshire.* — The spring rises in carboniferous limestone, at a temperature of 14° above that of the vicinity; contains saline ingredients, 2 grains in a pint (sulphate of soda and magnesia, and muriate of lime); evolves nitrogen only.
6. *Taafe's Well, near Cardiff.* — Rises from coal strata, at a temperature of 21° above that of the vicinity; contains saline ingredients, only 1·2 grain in a pint (sulphate of magnesia); evolves 96½ per cent. of nitrogen, and 3½ per cent. of oxygen.
7. *Mallow, Co. Cork.* — The Spa well rises in carboniferous limestone, at a temperature of 23° above that of the vicinity; contains saline ingredients, only 0·3 grain in a pint (carbonate of lime); evolves nitrogen 93½ per cent., and oxygen 6½.

It is very surprising that the only hot springs of Great Britain should all rise through strata of the carboniferous system (mostly below the coal), or through others which rest unconformably upon them.

* Dr. Daubeny places the source of this spring in red sandstone, but we conjecture that it is likely the spring originates in the mountain limestone which lies unconformably below the lias and new red sandstone.

Warm Springs of a Part of Germany, &c., yielding Carbonic Acid, &c.

Aix-la-Chapelle. — The Kaiserquelle rises at the junction of clay slate and carboniferous limestone, with a temperature 85½° above that of the vicinity; contains of saline ingredients 32 grains in a pint (muriate, carbonate, and sulphate of soda, &c.); evolves nitrogen 69·5, and carbonic acid 30.

Borset. — The Mühlenbend rises with the same geological relations as the last, with a temperature 121·5° above that of the place; contains of saline ingredients 34 grains in a pint (muriate, carbonate, and sulphate of soda, &c.); evolves nitrogen 80 per cent., oxygen 2, and carbonic acid 18.

Ems. — The Rondul rises in argillaceous slate, with a temperature of 81° above that of the place; contains of saline ingredients 28·9 grains in a pint (carbonate, muriate, and sulphate of soda); evolves carbonic acid gas only.

Wiesbaden. — The Kochbrunnen rises in chloritic slate, with a temperature of 108° above that of the vicinity; contains of saline ingredients 57·6 grains in a pint (muriate of soda, lime, and potash); evolves nitrogen 27 per cent., and carbonic acid 73.

(The above springs all rise in or adjoining the slaty rocks.)

Warm Springs of the Pyrenees.

Those of *Arles*, *Preste*, *Vernet*, and *Molitz*, in the Dép. des Pyrénées Orientales, having temperatures above the vicinity of 85·3°, 71·0°, 72·2°, and 40°; contain of saline ingredients 2, 1, 1·3, 1·3 grains respectively (sulphuret of sodium, &c.); and evolve nitrogen gas only. They rise from granite.

The following are in the same department: —

That of *Sorède*, having a temperature above the vicinity of 9°; contains of saline ingredients 6·8 grains in a pint (carbonate, sulphate, and muriate of iron); and evolves carbonic acid gas only.

Those of *Reynez*, *Enn*, and *Thuez*, having temperatures above that of the vicinity of 23·7°, 62·0°, and 71° have *almost no* *saline contents;* and evolve *no gases.* The two former rise in mica slate, the latter at the junction of granite and limestone.

Those of *Enaldes, Dorros,* and *Los* rise at the boundary of granite, with temperatures 47·1°, 44·4°, and 24·2° above the vicinity; contain very little saline admixture (1 grain hydrosulphuret of soda, &c.); and yield nitrogen gas only.

The waters of *Barège* and *Cauteretz,* in the Pyrenees (51·9° and 70·1° above the temperature of the place), rise in primary rocks, and yield nitrogen only.

The baths of *Loueche* (74·1° above the temperature of the place) yield nitrogen only.

To complete this view of the chemical characters of hot springs, we may notice some of those which rise in volcanic countries.

At *Mont Dor,* Cæsar's Bath rises in trachyte, with a temperature 52° above that of the country; contains of saline ingredients 11·4 grains in a pint (carbonate, muriate, and sulphate of soda); and evolves 9·85 nitrogen, 0·85 oxygen, and 90 carbonic acid.

The springs of *Chaudes Aigues,* near Aurillac, rise in gneiss, with a temperature 118° above that of the place; contain 14·5 grains of saline ingredients in a pint (carbonate and muriate of soda, magnesia, lime, and oxide of iron); evolve from 12 to 30 nitrogen, 1 to 15 oxygen, 57 to 87 carbonic acid.

None of the facts disclosed by chemical analysis of these springs, justify the belief that it is to any peculiar chemical action in their channels that their heat above the atmosphere is owing. On the contrary, their heat is derived by communication from *the heated rocks through which they pass,* whatever may be the cause of their chemical differences. (See professor Forbes's remarks, *Phil. Trans.* 1836, p. 576.) That the heat of the rocks, and therefore that of the springs, is derived from volcanic action, appears to Dr. Daubeny probable, because nitrogen gas, so commonly evolved from hot springs, is also a product of volcanos, both subaërial and submarine, and because "the majority of thermal waters arise, either from rocks of a volcanic nature, from the vicinity of some uplifted chain of mountains, or, lastly, from clefts and fissures caused by disruption."

These arguments, when taken in connection, appear to us to prove that the heat of the springs is derived from the *depths of the channels* in which they flow below the surface. The presence of nitrogen may establish the existence of substances, at considerable depths, capable of decomposing atmospheric air; but when we find that in volcanic Ischia a whole group of springs yields no nitrogen, and that it is not in volcanic regions, but on the borders of granitic elevations, and fractures of ancient strata, that nitrogen is most uniformly the predominant gaseous product, it seems unnecessary to appeal to local volcanic excitement for an effect which apreads both in time and area far beyond the traces of purely volcanic phenomena.

That hot springs are numerous in volcanic regions is a certain and even necessary truth; but they appear quite as abundant on the ancient lines of uplifted rocks, like the Pyrenees, where professor Forbes has traced so many to their origin at the junction of stratified and unstratified rocks, that it seems in that region almost an invariable concomitant circumstance.* "The general connection of the hot springs with the granite is so remarkable in that country, as to strike the observer at once; but there are several other peculiarities worthy of note. The abundance of hot springs increases in a very remarkable manner as we advance eastward in the range; nor can any one have a just idea of the prodigal abundance of these thermal waters, who has not visited the departments of the Arriège and the Pyrénées Orientales. Their temperatures are also the highest. In this part of the chain, granitic formations preponderate; yet in almost every case which I have examined, if springs rise in granite, *it is just at the boundary of that formation with a stratified rock.*

* Phil. Trans. 1836, part ii.

More striking instances of the immediate connection between thermal waters and disturbed strata, than the Pyrenees afford, cannot be desired. The same thing, however, is very generally true; even in England, under the Bath springs, at the Buxton spring, at the Bristol spring, the dislocations of the strata are very remarkable. In connection with professor Forbes's result, Mr. Henwood's curious observation, already stated, that the temperature of the waters issuing from the granite of Cornwall is always *lower* than that of such as flow from slate rocks at the same depth, deserves to be remembered. This is found to be the case at the surface, and to the depth of more than 200 fathoms.

Thermal springs are thus found to have, as their most general characteristic of origin, a peculiar geological position; — they burst forth (more remarkably than other springs) at points of extreme displacement of the strata, anticlinal elevations, &c., or, in general terms, at points where it is conceivable that a communication exists downward to the regions of interior heat. For this important generalisation we are indebted to Dr. Daubeny.

Further, it appears that these springs are scarcely less abundant or less heated in countries far removed from the regions of powerful volcanic excitement, than amidst active or extinct volcanos. Dr. Daubeny supplies an excellent catalogue of European springs, in his Report to the British Association, 1836; and Mr. De la Beche has collected examples of hot springs in all quarters of the globe.* The following brief summary will suffice for the purposes of reasoning on their geographical relations to existing volcanos.

In the British Islands, the average of 7 springs connected with carboniferous limestone gives an excess of temperature above that of the atmosphere of 28°.†

* Geological Manual, p. 17.

† St. Amand, near Valenciennes, in the same strata, has the same excess of temperature.

In Germany, the average temperature of 20 springs is 58·9° above that of the atmosphere.

In France, connected with its central volcanic chain, 12 springs average 69·2° above the air.

In France, connected with the granitic Vosges mountains, 4 springs average 80·2° above the atmosphere.

Connected with the Alps of Dauphiné, rising in Jura limestone, &c., 3 springs average 46·7° above the air.

Connected with the Pyrenees, 36 springs average 48·6° above the air.

Connected with the Swiss Alps, 16 springs average 44·8° above the air.

In Croatia, 5 springs average 58·2° above the temperature of the region.

In Styria and Carinthia, 5 springs average 44·6° above the temperature of the place.

In volcanic Hungary, 14 springs average 47° above the temperature of the air.

In volcanic Iceland, springs of various temperatures occur, from the boiling Geysers to a moderate warmth; the hottest being near the site of active volcanos.

In the volcanic island of Ischia, 6 springs average 55·9° above the air.

In Sicily, 2 springs average 55° above the air.

In Italy generally, 19 springs average 52·4° above the air.

In Sardinia, 4 springs average 57·7° above the air.

In Corsica, 2 springs average 59° above the air.

In Portugal, 35 springs average excess of temperature above that of the country about 30°.

In the Caucasus, average of those mentioned by De la Beche, about 60° above the air.

In the Himalaya, on the Jumna River, the temperature of springs appears to exceed that of the air at least 80°.

In China, 3 springs, which issue from granite, probably exceed the temperature of the air from 70° to 120°.

In Japan (*volcanic*) is a boiling spring.

In Ceylon are springs which exceed the mean temperature about 30°.

On the American continent, the most remarkable collection of springs is on the Ozark mountains; the 70 springs, which here rise in slate rocks, have temperatures which exceed those of the vicinity by 40° to 100°. Others occur in the Rocky Mountains.

In Jamaica, the bath springs in St. Thomas in the East are about 50° above the mean temperature.

It is to be regretted that the information concerning the temperature of hot springs is, in general, insufficient to determine whether they suffer periodical variations with seasons or cycles of years. Until lately, the means of instrumental research were inadequate for delicate experiments such as those required in this branch of study, nor has much been done to furnish future observers with the power of settling these questions. It appears probable that thermal springs may vary their temperatures, because it is an established fact, that a part of the contents of some of them is withdrawn, by cutting off their connection with subterranean springs of cold water.* Variation of temperature is asserted as a fact, in respect of the spring of Gargitello in Ischia, Pfeffers Baths, a spring at Cannea in Ceylon, and Bagnères de Luchon in the Pyrenees. During earthquakes and volcanic violence, thermal springs have been affected, both in their quantity and in their temperature: in 1755, the year of the Lisbon earthquake, the temperature of the Source de la Reine at Bagnères de Luchon was raised 75°. In 1660, a great earthquake desolated the country from Bordeaux to Narbonne, displacing large masses of ground, and caused *one of the hottest of the Pyrenean springs* to become so cool as to be no longer of any value. (Kircher, *Mundus Subterraneus.*) On the contrary, two springs in South America, far from any native volcano, have increased in temperature by 4° centigrade, in the interval between an observation by Humboldt and its repetition by Boussingault. (Forbes, *On Pyrenean Springs, Phil. Trans.* 1836.)

The general conclusions fairly derivable from a study of thermal springs are few but important. Their heat

* This appears to be ascertained in the case of the hot spring of Aix, in Provence; and though, in the late diminution of the Bath waters by sinking a well in Bath (1836), the new well was filled by warm water, it was believed, that during the sinking of the Batheaston Trial coal pit, the Bath waters were reduced. The water was slightly warm in the Batheaston pit, if we correctly remember the statement of Dr. Smith, who was employed on the occasion.

is not the effect of local causes peculiar to each locality, but is communicated to water which has fallen on the surface, and penetrated to great depths in the earth. Returned to the surface by hydrostatic pressure, these springs bring with them the temperature of the interior, modified and slightly diminished by the comparatively cool rocks near the surface of the earth. This diminution of their heat is perhaps but slight, owing to the feebly conducting power for heat which the rocks possess; yet upon some very small streams it may have a powerful influence. Most of the very warm waters, as those of Bath, Aix-la-Chapelle, the springs of Nassau, and the Pyrenees, are very abundant. To see these rivers of hot water pouring forth for a thousand years undiminished in heat or abundance, is one of the most remarkable and even (as professor Forbes truly says) romantic circumstances which fall under the notice of geology. The conclusion to which they obviously point of the existence of a general heat below the surface of the earth, is indisputable, whether, with Dr. Daubeny, we view that heat as the result of chemical action, and call it volcanic, or, with Humboldt and Arago, regard it as the residue of the original ignition (*chaleur d'origine*) of our planet.

Experimental Inquiries into the Heat of the Globe.

That the earth has below its surface a source of *great heat*, independent of solar influence, is perfectly ascertained by volcanic phenomena; that this heat is very *generally diffused*, is equally certain, from the extent of country in which thermal springs are found; that it is *universally spread* below our feet, becomes continually more and more probable from experimental researches in countries uninfluenced by any chemical actions supposed to go on at the base of volcanos, where no hot springs burst to the surface, and where the fractures of the strata yield both pure and mineralised waters at common temperatures. Before, however, stating the important facts thus established, it is convenient to direct attention to the conditions of the experiments; for thus the truth and applicability of the inferences drawn from them will more clearly appear.

No truth is more firmly established in meteorology, than the *primary* dependence of the temperature of each point on the earth's surface upon the calorific influence radiated from the sun. The evidence is found in the conformity of the diurnal and monthly changes of temperature, at each place, to the changing position of the sun, and the proportionality of the annual mean temperatures at different places to the quantity of solar rays received.

Neither of these satisfactory parts of evidence can, however, be completely gathered, except by long averages of years, which neutralise the irregularities of particular years; nor properly understood, without attending to many secondary influences.

The heating influence of the sun, though continually acting, has not been found to have any cumulative effect on the globe; which, *upon the whole*, has perhaps undergone no perceptible change in this respect since the reach of history; but many parts of its surface have experienced real alterations of climate from drainage, inclosures, destruction of forests, and other causes. There is a cooling as well as a heating power constantly at work. The earth is a warm body plunged in a relatively cold medium, for the planetary spaces are cold compared to our globe, and the incessant radiation from the surface of the earth into the vast spaces around is uncompensated by any counteracting influence, though diminished in the cold regions of the world by peculiar provisions of a beneficent Providence.

The temperature of the ethereal spaces around is supposed to be pretty well represented by the minimum of observation on the earth's surface, during the long absence of the sun. It is therefore generally taken at about 50° centigrade, below the freezing point,

— a supposition confirmed by some astronomical considerations, and sanctioned by Fourier and Swanberg.

Preserving between their joint effects a variable equilibrium of temperature at the surface of the earth, the calorific power of the sun and the refrigerating influence of the planetary spaces affect every point on the terraqueous globe; and, as far as geographical position with respect to the poles and equator is concerned, the result may be nearly calculated. The mean temperature of any zone of land and sea is, in fact, nearly proportional to the cosine of its latitude.*

But the globe is enveloped in an atmosphere, which produces further modifications of climate, according to the elevation of places above the level of the sea. The sun's rays traverse this atmosphere without heating it; the warmth which it possesses is derived from the earth by conduction, and dissipated by radiation. Owing to the diminution of density in the upper regions of the atmosphere, the air heated near the earth's surface expands into larger and still larger spaces as it rises, and thus the upper parts of the atmosphere have a temperature always growing lower and lower as the density grows less and less. The variations of heat in the atmosphere are greatest at and near the earth's surface; they may become insensible in the upper aërial regions, above the clouds. The cold, thus permanently fixed in the high atmospheric spaces, necessarily reacts upon the land which is raised above the general level of the sea. The temperature of the surface of such land is the resultant of the general influence of the sun, planetary spaces, atmospheric modifications, and conducting power of the ground. In general, the effect of elevation above the sea level in diminishing the heat of the surface of the ground, is nearly in proportion to the

* The mean annual temperature of the equator being taken at 81·5°, that of any other lat. = 81·5° × nat. cosine lat. This is in error toward the north pole, owing to the distribution of land and water, which makes two poles of maximum cold in Asia and America, nearly coincident with the magnetic poles. See a paper by sir D. Brewster (Transactions of the Royal Society of Edinburgh).

height, in all latitudes.* Hence it happens, that as the mean temperature of the equator is about $81\frac{1}{2}°$, the height in the air at which the mean snow line should be found $= 49\frac{1}{2}° \times 352$ feet $= 17,424$ (obs. 16,829), and in any other lat. $= (81\frac{1}{2}°$ N. cos. lat. $- 32)$ 352. In W. lat. 56° 50′, nearly that of Ben Nevis, this gives $(44{\cdot}6 - 32{\cdot})\ 352 = 4435$ feet; and as Ben Nevis is 4350 feet high, and is not covered perpetually with snow (which melts in July and August, except in shaded parts), the rule appears exact enough for the longitude of Britain.

Another cause productive of differences of temperature on surfaces equally exposed to the sun's influence, is the peculiar distribution of land and water; for these dissimilar parts of the globe unequally absorb and unequally give out heat; and one of them diffuses itself so as to obliterate many original differences of climate. Thus, on different circles of longitude, places which, having the same latitude, should have the same mean annual temperature, may, and do, differ in this respect several degrees, from the dissimilitude of the ground, and from the different relations they bear to the masses of land and surfaces of sea. Under the equator the land is generally hotter than the sea; towards the poles the reverse obtains. The sea climate admits of less extreme variations from the torrid to the frigid zone, than the land, and sea-shores participate in this mildness. Thus we have oceanic, littoral, insular, and continental climates, which differ sometimes by several degrees. The formula, therefore, given above (which expresses the average mean temperature in terms of the latitude) requires modification from this cause, as sir D Brewster has shown in the essay already quoted. From what has

* About 1° of Fahrenheit for every 100 yards of ascent is a common correction used with the mountain barometer. A more exact proportion is supposed to be 1° for every 352 feet, as found by comparing Geneva and Great St. Bernard. Mr. Atkinson, in Memoirs of the Astronomical Society, Professor Challis (Cambridge Phil. Trans.), have treated the subject mathematically. A general view of the state of knowledge on the distribution of terrestrial heat may be found in Professor Forbes's Report on Meteorology to the British Association.

been said, it is plain that the principal causes which influence the earth's surface temperature are known. One of the circumstances which mask the regularity of the results, and their real dependence on the position of the sun, is the *delay* which occurs between the moment of exertion of the greatest heating and cooling power and its visible effect on the surface of the land and sea. In the influence of the moon on the tide, we have an instance of the same kind lately reduced to law: the highest tides take place after the moon has passed her point of power. Just so the warmest epoch of the day is after the sun has crossed the meridian, when most rays fall on the earth: the hottest and coldest epochs of the year follow by an interval of about three weeks (in northern latitudes) the summer and winter solstices. When these allowances of time are made, and the local circumstances previously adverted to allowed for, the coincidence of calculation for hourly, daily, monthly, and annual temperatures, with the result of *long continued* and *regular* observation, is surprisingly close, and fully justifies the general conclusion that the earth's surface temperature is the balance of the variable heating energy of the sun and the uniform cooling power of the ethereal spaces in which the earth's orbit is situated. (What effect on surface temperature the peculiar condition of the interior of the earth may occasion, will be seen hereafter.) This being established, we may appeal to observation for proof that it is at the surface of the earth the greatest variations of temperature take place, and from this surface they are propagated upwards *with diminishing force* into the air above, and into the water and earth below, till in each direction they terminate, or become insensible. The communication of solar heat into the earth constitutes the first branch of our inquiry, and it has been quite sufficiently prosecuted to authorise the following positive statements.

1. By Leslie's experiments, made in 1816, 1817, at Abbotshall, in Fife, with *long thermometers*, plunged in

the earth at depths of 1, 2, 4, 8 feet, their stems rising above the surface, so as to be easily inspected, we find that the variations of temperature continually diminish downwards; — at 1 foot, the extreme monthly differences corresponding to summer and winter were 21° and 19.6°; at 2 feet, 16·5° and 16·3°; at 4 feet, 12·8° and 11·5°; at 8 feet, 8·0° and 8·2°.

2. The epochs of highest and lowest temperature continually differ more and more from the summer and winter solstices, according as the depth in the earth is greater; or, in other words, the time taken by the sun's rays to penetrate and warm the ground augments with the depth.

Thus, at 1 foot from the surface, January is the coldest and July the hottest month; at 8 feet from the surface, February and March are the coldest months, and September the hottest.

3. The average mean temperature of the year augments from the surface downwards; but does not reach the average of the air temperature, in the range of these experiments.

These results have been more than confirmed — they have been enlarged — by the experiments of Arago in Paris, Quetelet in Brussels, and Forbes in Edinburgh, and extended to the depth of 25 feet. M. Quetelet has founded on the experiments at Brussels a mathematical investigation of the highest interest.

Among the data for computation employed by M. Quetelet are experiments analogous to those of Leslie, made in 1762 at Zurich by M. Ott; a series made at Strasburg by Herrenschneider, in 1821, 1822, and 1823; another at Heidelberg by M. Muncke; one made at Upsal in 1832-3, by M. Rudberg; others at the observatories at Paris and Brussels descending to 25 feet. The original memoir* must be consulted for the mathematical part of the subject; but we shall present the conclusions which the investigation has established.

* Sur les Variations des Températures de la Terre. Bruxelles, 1837.

1. In descending from the surface of the earth, to depths continually augmenting, the *mean temperature of the year augments* gradually; yet, immediately below the surface, and at depths of half a foot or a foot, the mean temperature is found to be a *minimum.*

2. The *rate* at which the annual variations of temperature are transmitted to the interior of the earth, may be estimated at 6 or 7 days for 1 foot thickness of earth.*

3. Observation and theory agree in showing that the *extreme* temperatures of the year decrease in geometrical progression, while the depths below the surface are taken in arithmetical progression.

4. The *annual* variations of temperature may be considered as insensible at depths from 60 or 75 feet; that is to say, at the depths where the maxima and minima will occur at the same epochs (after an interval of one year!) as at the surface.

5. On descending several feet below the surface, the *annual* variations of temperature are as the sines of the elapsed times, in a circle whose circumference corresponds to the period of one year.

6. When different latitudes are compared, it appears that the *annual* variations of temperature penetrate to the least depths in the higher latitudes.

7. The *rate* with which *diurnal* variations of temperature are transmitted to the interior of the earth, may be stated at somewhat less than 3 hours for 1 decimètre in thickness (3·9 inches English).

8. The *diurnal* variations become insensible at a depth of 1·3 mètre (51 inches), which is 19 times less than the depth reached by the annual variations, as theory also indicates.

The important conclusion of the entire disappearance

* Forbes's experiments *in different sorts of rock* show the effect of these, in modifying the *range* of subterranean temperature, in altering the *rate* of its progress, and changing the epochs of *maximum* and *minimum* temperature. (Edinb. Trans. 1846.)

of all trace of annual or diurnal variation of temperature at a depth so moderate as from 60 to 100 feet, is perfectly confirmed by the well known experiments in the caves under Paris; and is the more satisfactory, that it falls much within the limits assigned to the annual variation by Fourier in his mathematical theory of heat.

The condition of the interior of the earth below the point of invariable temperature cannot be assumed upon any ground of probability independent of geological observations, nor foretold by any mathematical theory of heat, nor determined by any experiments made at the surface; but may be easily detected by direct thermometric experiments, even at the moderate depths already reached by human enterprise. If the earth be very cold within, the influence of the interior cold will begin to be felt below the depth of 100 feet; if very hot within, the rate of increase of this heat may be inferred from exact and numerous observations.

The experimental inquiries for this object have been prosecuted with great success in Europe, and partially in America, to depths amounting in England to 1584 feet (at Monkwearmouth), and about 1800 feet in Mexico. They consist of three divisions. In the first case, the experiments are made in or very near to mineral veins, which, by their character of filling fissures on lines of disruption, remind us of the general geological conditions of appearance of hot springs; the second set of experiments takes place in collieries and other excavations of like nature, among the stratified rocks, with or without dislocations. In each of these cases, either the temperature of the rock, of air, or of a constant subterranean spring may be tried. In the third case, wells or boreholes are sunk, in a country where little or no water naturally springs to the surface, to considerable depths, and till strong streams of water are let up, bringing with them the temperature of the subterranean regions at those depths.

First Class of Experiments. Metalliferous Veins. (*From Daubuisson's Traitè de Géognosie.*) The degrees are centigrade.

In the middle of the last century, Gensanne, director of the mines of Giromagny (Vosges), concluded that

At 100 mètres depth, the temperature was 12·0°
308 - - - 18·8
432 - - - 23·1
Ratio deduced, 333 mètres = 11·1° centig.
or 30 - = 1·0 —

M. Daubuisson made, in 1802, a large series of experiments on the waters in the mines of Freyberg, where the mean surface temperature is 8° cent. The general results are contained in the following table.

Depth in Mètres.	NAME OF THE MINE.			
	Beschertglück.	Himmelfahrt.	Kühschacht.	Junghohebirke.
0	8°	8°	8°	8°
80	- -	- -	- -	10
100	- -	10	- -	10
120	10	- -	- -	11
160	- -	- -	- -	12½
180	- -	12½		
200	- -	- -	- -	14
220	12½	- -	12½	
240	- -	14	- -	15
260	14 & 15	14½	14	
280	- -	- -	- -	16
300	15½	- -	15 & 16	
320	- -	- -	- -	17

The general result is an augmentation of 8° for 300 mètres; or, all observations included, 1° for 40 mètres: if the extremes alone be taken, 1° in 35 mètres.

This conclusion was confirmed by new experiments, in 1805, under the direction of Mr. Trebra. The temperature of the rock was now tried, with great care, for two years, the observations being registered thrice in each day. The temperature never varied in this time.

At the surface (as before)		8°
180 mètres	-	11¼
260	- -	15

as M. Daubuisson had found in 1802.

The ratio deduced is about 1° in 37 mètres in the upper part. and 1° in 22·2 mètres in the lower part.

Again, under the same direction, thermometers placed in gneiss in the mine called Alte Hoffnung Gottes, gave

At the surface (as before)		8·00°
72 mètres	-	8·75
170	- -	12·80
270	- -	15·00
382	- -	18·75

From these experiments it is concluded that the augmentation of temperature is 1° in 38 mètres.

In the mines of Poullaouen and Huelgoat, in Brittany, M. Daubuisson found results which he considered to be partly influenced by local causes. In Poullaouen, at 140 fathoms, the augmentation was 3·1° or 1° for 45 mètres. In Huelgoat, at 230 mètres, the augmentation was 8·7°, or 1° in 26·4 mètres.

In Cornwall, Mr. Fox's obervations, at various periods, yield corresponding results. In a spring Dolcoath copper mine, 439 fathoms deep, the temperature was 27·8°, and that of the surface 10°.

In the same mine, 421 fathoms deep, the temperature of the rock of a gallery for 18 months was 24·2°.

Lately (1837) Mr. Fox communicated to the British Association some further observations, made *below the lowest workings*, in the Levant tin and copper mine, and the consolidated copper mine. At 230 fathoms from the surface, in the Levant mine (in granite), a thermometer, sunk 3 feet below the " sump," stood at 80°; another, sunk only a few inches, was at 78·5°; and the air in the mine 67°. At 190 fathoms, the corresponding indications were 78°, 72·5°, and 67°. The general ratio is 1° Fahr. for 46 feet English; or, allowing 10 fathoms to the invariable temp., 1° in 46 feet.

In the consolidated mines, at a depth of 290 fathoms, thermometers sunk in a cross course of the rock (killas) indicated at the vein 92° and 88°; 10 fathoms from it, 86·3° and 85°; 24 fathoms from it, 85·3° and 84°. Here the metallic vein is the hottest part; Mr. Fox thinks, because of its allowing hot waters to ascend. The temperature 85·3° is at least 35° above that of the climate, and the ratio is consequently 1° in 49·6 feet; or, allowing 10 fathoms to the depth of variable temperature, 1° in 48 feet.

And still more lately, experiments made by Captain Oats in Tresavean copper mine gave the following results.

Depth.		Air.	Rock. No. 1.	Rock. No. 2.
26 feet	In granite	53·3°	57·0°	52·8°
200	lode	77·2	76·0	75·5
200	again	77·7	76·0	75·5
250	lode	83·2	82·5	82·0
262	lode	85·5	82·5	82·0

Ratio, 1° in 48 feet from the surface; or,
1° - 46 - from a point 10 fathoms below surface.

Humboldt observed, in mines near Guanaxuato (Mexico),

At 502 mètres depth in	Valenciana mine	36·8°	centig.
193 -	Rayas	33·7	—
134 -	Villalpand	29·4	—

The surface temperature is 16°. The volcanic character of the country is perhaps unfavourable for accurate inferences.

Second Class of Experiments. In Stratified Rocks.

Saussure, in the salt mines of Bex, found

At 108 mètres depth the temperature	14·4°
183 - - -	15·6
220 - - -	17·4

Ratio deduced, 1° centigrade for 37 mètres.

Mr. Hodgkinson, at the request of the British Association, has made some experiments in the comparatively shallow salt mines of Cheshire which evince an augmentation of 1° in 70 feet from the surface.

But the greatest strength of observation, independent of mineral veins, has been concentrated in the coal districts. Mr. Bald, Mr. Buddle, and other observers, have long since collected much information in the collieries of the Tyne and Wear; of which, however, we can make only partial use, because the experiments were mostly made on the air, which, for many reasons besides miners' lights and chemical actions, is unlikely to yield accurate ratios, such as are now attainable.

The following are some of Mr. Bald's results, published in the Edinburgh Royal Transactions. The scale is Fahrenheit's.

Whitehaven. — Spring at surface - -	49°
480 feet - -	60
Ratio from surface, 1° for 44 feet.	
Workington. — Spring at surface - -	48°
504 feet - -	60
Ratio from surface, 1° for 42 feet.	
Percy Main Colliery, Northumberland. — Mean temperature at surface - -	49° *
900 feet depth -	70
Ratio from surface, 1° for 43 feet.	
Jarrow colliery. — Surface assumed - -	49·5°
Water at 882 feet - -	68·0
Ratio from surface, 1° for 48 feet.	
Killingworth colliery. — Surface assumed -	48°
Water at 1200 feet depth -	74
Ratio from surface, 1° for 46 feet.	

The near accordance of these results is remarkable. The ratios are all in error by a small quantity, because no allowance is made for the depth of variable heat.

* It is really under 48°. — *Author.*

It is a very usual and easy objection to these results, that the lights, the respiration of horses and men, pyritous decompositions, &c. raise the temperature. The contrary is generally true, as we have shown in narrating the particulars of an experiment (1834) at Monkwearmouth, where the coal had been reached only a few days previous, no horses had entered the mine, few miners were at work, no chemical decompositions apparent, and the *air supposed to be heated* was many degrees cooler than the coal and rocks, and grew hotter only in proportion to their influence.* The depth of this pit was 1584 feet; mean temperature at the surface 47·6°; thermometer at the bottom, in coal, 71·5°, 72·0° and 72·6°. Ratio deduced 1° Fahr. for 20 yards English.

This ratio, lower than Mr. Bald's, derived from the water in the coal mines, may perhaps be more correct; and it is supported by experiments at Wigan, under the care of Mr. Peace, which give 60 feet for 1°. At Manchester, Mr. Hodgkinson obtained a ratio from the surface, of 1° in 69 feet; while at Bedminster, under the care of Mr. W. Sanders, the ratio was found to be as high as 1° in 30 feet, and some anomalous facts were observed. (In each case 100 feet are deducted from the depth as an allowance for the depth of variable heat.)

M. Cordier gives the following summary of observations in the coal mines of Carmeaux, Littry and Decise (1827)

Carmeaux.

Water in the well Veriac,	at 6·2 mètres	12·9° cent.
Bigorrè	11·5	-	13·1	—
Rock at the bottom of Ravin mine	181·9	-	17·1	—
Castellan	192·0	-	19·5	—

* Phil. Mag. and Annals, 1834.

Littry.

Surface temperature	-	0 mètre	11·00° cent.	
Rock at the bottom of St. Charles mine	- - -	99	-	16·13 —

Decise.

Water of the well Pelisson	at	8·8 mètres		11·40°	—
Puits des Pavillons		16·9	-	11·67	—
Rock in the Jacobè mine	-	107·0	-	17·78	—
Ditto	-	171·0	-	22·10	—

The general result of a complete discussion of these observations on subterranean temperature made in mines and collieries, appears, to give a ratio of 1° cent. for about 25 mètres, or 1° Fahr. for 45 feet English.

Mr. Henwood's observations on subterranean temperatures in the rocks, made on the waters issuing from them, extend to no less than 95 in slate, and 39 in granite, and from the surface to 200 fathoms and upwards. The following is a summary.

Slate.			Granite.		
Average Depth.	No. of Observations.	Temperature.	Average Depth.	No. of Observations.	Temperature.
35 ft.	21	57·0°	31 ft.	7	51·6°
73	19	61·3	79	17	55·8
127	29	68·0	133	12	65·5
170	21	78·0			
221	5	85·6	237	3	81·3

Thus at all depths the slate appears to be about 3·9° warmer than the granite at the same level.

The progressive increase of temperature in descending is in a mean of

95 observations on slate 1° for 6·5 fathoms (39 feet).
39 - granite 1° - 6·9 - (41·4).

(*Reports of British Association* for 1837.)

The *Third Class* of experiments includes chiefly Artesian wells. One of the most important is the well of La Rochelle, described by M. Fleuriau de Bellevue. The mean temperature of the district is

Air at the surface	- - -	1·87°
Water in the well, at 316 feet depth	-	16·25
Ditto	369½ - -	18·12

Ratio from surface, 1° cent. for 58·5 to 72 feet, or 20 mètres.

At Southampton, a well 133 yards deep was found to have a temperature of 56½° Fahr.; the mean temperature of surface being 50°. The ratio deduced is 1° Fahr. in 46 feet English.

The importance of this branch of evidence induced M. Arago to publish a short but valuable notice of Artesian wells, which is inserted in Jameson's Journal for 1835, p. 235. The following table is extracted, and the ratios appended to each observation: —

		Mètres.	Ratio.
Paris.—Mean temp. of surface	10·6°		
Well of Port St. Ouen	12·9	66	1° in 29·0°
Département du Nord.—Mean temp.	10·3		
Well of Marquette	12·5	56	1 - 25·5
Aire	13·3	63	1 - 21·0
St. Venant	14·0	100	1 - 27·0
Sheerness.—Mean temp. of surface	10·5		
Well - -	15·5	110	1 - 22·0
Tours.—Mean temp. of surface	11·5		
Well - -	17·5	140	1 - 23·3

Mean result, 1° cent. for 24·6 mètres; or,
1 Fahr. for 45 feet.

The coincidence of this with the former result is unexpected.

The conclusion from experimental observation is in harmony with that authorised by hot springs, that the earth has a general and pervading high temperature below the surface.

CHAP. X.

STATE OF GEOLOGICAL THEORY.

ALL branches of the study of nature, in their progress from the period of observation to that of generalisation and theory, appear destined to endure the same storm which astronomy has weathered; and, like that noble science, to come forth renewed and purified in the struggle; strengthened by popular applause, and fertile of public benefit.

To quicken the inertness of prejudice, and rouse the despair of ignorance, among the masses of mankind, may appear unnecessary for the "advancement" of science, which must ever be intrusted to a few superior minds; but the opinion which would separate the acquisition from the diffusion of knowledge is no less erroneous than ungenerous, since the highest and most comprehensive truths in natural science are but the concentration of common phenomena, the laws of common experience. In the determination of these phenomena, in the correct association of them into laws and systems, immense preliminary labours must be undergone before the most powerful intellect, however deeply versed in abstract science and the philosophy of causation, can ascend to that comprehensive view of a whole series of dependent truths which constitutes a general theory.

Perhaps no term of importance in estimating the state of science is employed in more various and inconsistent senses than this word theory, which few branches of human knowledge have ventured to claim, but which is actually used as a term of reproach by men entirely ignorant of them. When correctly used, with the masters of Inductive Philosophy, it signifies the high point to which every faithful inquirer after truth is advancing, however slowly, in his peculiar branch of study; it is the unchangeable summit of a cone whose base continually enlarges to include every known fact appertaining to the subject; and whose every part is linked in harmony according to one simple and intelligible principle. Science is perfect only when it is in the form of a truly general theory; and perhaps it is not too much to believe that the utmost efforts of the human mind may fail in the attempt to comprehend all natural phenomena perceptible by our organisation in *one such theory*.

Even if, hereafter, it should be found possible to include the most comprehensive theory of ponderable matter, gravitation, and the undulatory theory of light and heat, into one wider generalisation for all inorganic matter, there would still remain the mysterious phenomena of life; and beyond all these the relation of mind and sensation. Now these are a few of the legitimate branches of the study of nature, which the providence of the Almighty Creator of the universe has committed to human reason. Their development is for man a physical revelation, continually enlarging its power and influence on the mind and heart; yet it leaves, almost without touching, except to support, a large circle of moral and religious truths of yet higher importance, and more lasting and powerful interest.

Geology dares not claim, as yet, the possession of a sound and general theory, such as is here described; but in common with astronomy, and chemistry, and mechanics, and every other part of natural science, its infancy was amused with baseless speculations, and hypotheses which have fallen into contempt. For these errors of their fathers its modern cultivators have dearly paid, and fairly atoned. The wanton and ignorant abuse lavished on the magnificent problems to which their lives are devoted, has been endured with patience; the principles which have guided other and easier branches of philosophy in their successful progress, have been wisely copied; they have begun at the foundations of the temple of truth; they have collected an inconceivable number of individual facts; they have combined these into correct, though incomplete, generalizations; and have called on zoology and botany, on chemistry and mechanics, to furnish the interpretation.

Geology has thus been placed, by the energy and prudence of its living advocates, in the circle of inductive science; no more to be dissociated from the other parts of knowledge; advancing with them, and often leading them forward, by the proposal of new and remarkable problems, to the solution of which all the collected resources of modern science are sometimes scarcely equal. In this career the Geological Society of London has proceeded, without faltering, for thirty years, and the reward of their labours is in the just and candid acknowledgment of one most competent to pronounce, that "Geology, in the magnitude and sublimity of the objects of which it treats, undoubtedly ranks, in the scale of the sciences, next to astronomy." *

If the object of this treatise were to produce merely the entertaining parts of geological discussion, it might be very proper to introduce a notice of the many fanciful and absurd systems of cosmogony and philosophy, falsely called "theories of the earth." Perhaps, notwithstanding the discredit which such mistaken attempts have brought upon philosophy generally, rather than geology in particular, some useful result might be derived from a dispassionate survey of them. For if Woodward, Whiston, and Burnet, — Buffon, De Luc, and Werner, have failed in the great attempt to unveil the natural history of the earth, it was not so much because of any inferiority of intellect, want of patient research, or deficiency of information, that their "theories" have fallen into oblivion; but because the

* Sir John Herschel, in his Discourse on the Study of Natural Philosophy, p. 287.

process of induction, without which no true theory can arise concerning the works of nature, was not at all, or imperfectly followed out.

There has been, moreover, from early times, in consequence, perhaps, of an imperfect apprehension of the nature and object of revealed religion, as compared with the physical truths which are left to the discovery of human reason, a singular propensity to supply the deficiency of philosophical research by arbitrary appeals to the authority of scripture. The danger to religion of such a reckless course is too well understood by the enlightened theologians of this age to render more than a passing remark necessary; though, even in the nineteenth century, it occasionally happens that astronomical truth is questioned, because the scriptures, addressed to an unlearned people, speak popularly of the sun "standing still;" and the established inferences of the successive revolutions in the state of the globe, which are not mentioned by Moses, but which invest with new interest the study of the ancient earth, are thrown aside in favour of some physical and theological absurdity, such as that which makes the stratified crust of the earth the effect of one tumultuous flood, and turns the "fountains of the great deep" into submarine volcanos, or hides a world of waters within the globe.

The mention of these unhappy errors would be painful, could we believe that the progress of pure religion or sound philosophy could be checked by their influence. Let it be remembered that the Bible teaches no physical science, and that philosphy has made little progress in physical truth, if it does not recognise among all the multiform changes of the universe the power and the will of ONE SUPREME. From this highest point of true philosophy, as from a sure foundation, a pure religious faith must spring. Of the importance and independence of physical truth none of the distinguished ornaments of the Christian faith, from St. Augustin to Boyle and Chalmers, have been ignorant; and to their immortal works we beg to direct the attention of those inconsiderate persons who think to advance Christianity by denying philosophy, and to confirm revelation by making its very truth depend upon their own narrow interpretations of nature.

Lest, however, we should fall into as great absurdities of another kind as these we have mentioned, it will be prudent to determine, if possible, the true character of a general theory of the earth; for in this there is a great liability to error. Geology, regarded as a body of facts, comprises not exclusively, nor specially, the phenomena which are now, or have been at any one former time, in progress on and within the earth, but embraces the whole succession of these occurrences, from the earliest operation of natural laws on the globe to the present hour. Each of the phenomena, taken singly, is the subject of interpretation by some special branch of natural science: the characters of organic fossils are referred to the zoologist and botanist; mineral compounds are examined chemically and crystallographically; the fractured crust of the earth receives explanation from the application of mechanical philosophy. The general view of these and other phenomena, manifested at one epoch, or during one period, and the survey of the condition of the globe at several such periods, are the proper objects of *geological observation;* and the successive states of the globe being thus ascertained, it is the business of *inductive philosophy* to discover the general antecedent condition or proximate cause upon which these successive states depend. If the research be successful, the result is a *general theory of the earth;* that is to say, a sufficient natural cause is found to explain, in combination with other agencies really existing, all the characteristic changes which have been observed in the earth's condition, in the degree, combination, and sequence which actually belong to them.

Perhaps an illustration may be usefully taken from exact science. In mathematical inquiries, a particular result or condition of things is frequently capable of distinct representation by means of a series of quantities, unequal in value, and combined in different proportions; yet the origin, formation, and succession of this series of dissimilar combinations of unequal quantities may be perfectly simple, and often is perfectly known, though the series be demonstrably boundless in one direction. Now, in this case, the "theory" of that series is really known; and, in exactly the same sense, the "theory" of the series of dissimilar combinations of unequal phenomena, which succeeded one another in a certain order of time, upon and within the earth, appears attainable by the human intellect.

Every attempt to ascertain the *law of succession* among the phenomena manifested in the structure of the earth must entirely fail, unless, at least, the characteristic facts, and combinations of facts, belonging to each successive geological period be completely known, and these periods completely defined. It is therefore necessary, before noticing the attempts which have been made to establish a geological theory, to ascertain how far these indispensable preliminary conditions have been fulfilled. The historical view of the series of stratified rocks, contained in the first part of this work, will show to what extent the author has been able to reduce to rule and system the known phenomena occasioned by the action of water on the globe; in the succeeding part a similar attempt is made to unfold the parallel series of truths concerning the unstratified rocks, and other effects of heat. Though neither of these attempts ought to be taken as a measure of the progress made in similar inquiries by other individuals, and still less as a summary of the whole knowledge on the subjects, the intelligent reader will easily perceive that, with regard to the mechanical and chemical agency of water in depositing earthy sediments, and the changes of organic life on the globe at several successive epochs, the monuments of nature have been extensively collected, ranged in their real order, and in a great measure truly interpreted. Very large portions of the land and sea are however still unknown in this respect.

Hardly so much can be said regarding the effects of heat; for though these are for the most part clearly, they are not completely, interpreted, nor is the *order of their succession* sufficiently known. It appears, however, that the products and effects of heat *at different times* have not varied so much as those of water, so that the order of succession among them is of less importance.

In a complete geological theory, not only the order of succession among the several groups of phenomena would be deducible from the principles on which it was based, but also, in proportion to the completeness of the facts indicating the lapse of time, the real duration of the several successive geological periods would be at least approximately known. It would be very unwise to attempt this at present, because of the imperfection of the data in every part of the series of strata; and in this respect geological theory is not singular, for even the most perfect mathematical theorem is equally inapplicable to incomplete data. This was strongly felt by the geologists of England, who gave a fair proof that hypotheses were out of fashion, when they declined to compete for the medal which the Royal Society offered to encourage researches into the antiquity of the globe. (See on this subject of geological time, Vol. I. chap. i.)

It may perhaps be thought, that the limits which have been fixed for a legitimate "theory of the earth" are sufficiently wide to include an immense number of general speculations; and that many conflicting hypotheses, advanced by Neptunists and Plutonists, should now be compared and condemned. But, in truth, a little consideration will prove that there have not been, and can never be, more than two hypotheses really general on the subject. Nature, as we see it, exists under the influence of particular forces and conditions, vital, chemical, and mechanical; and the sum of the phenomena that now occur in a given time is the measure of those forces and conditions. The exterior influence of the sun, and the ethereal spaces; the mass and quality of the atmosphere; the size, figure, density, and motions of the earth; the distribution of land and sea, — are all circumstances of great importance, to which the vegetable and animal productions of the globe, as well as the chemical and mechanical operations upon it, are adjusted.

It is soon apparent to the inquiring mind, that many of these conditions and forces vary, and with them, from time to time, suddenly or gradually, the characteristic phenomena of life and inorganic matter. If we knew the *measure of these variations*, the real state and momentary condition of the earth at the present, in former, and in future periods, would become a practicable problem.

Now it must be evident that we have not such knowledge; for the variations in question, though quite sensible, are too complicated to be understood, except through an immensity of recorded observations; and of these we have few that are trustworthy, except in astronomy. In astronomy, *with the help of the general theory*, it has been found possible to determine the "limits of variation" due to the disturbing forces of the planetary system; but it is impossible to effect this in geology, from a survey of existing nature, *for want of such a theory*. Incapable, therefore, of learning from the most perfect survey of nature as it is, whether terrestrial phenomena are subject to progressive and permanent changes, or to a limited circle of compensating variations, the leaders of geological speculation have assumed one or other of these views — the only really general ones which the subject permits; and thus we have, on the one hand, Leibnitz deducing the principal geological phenomena from the gradual refrigeration of an ignited globe; and, on the other hand, Lyell, and the followers of Hutton, maintaining the sufficiency of "modern causes," acting with their present intensity, to account for all, even the earliest traceable changes of conditions of our planet. The real distinction between these celebrated speculations consists not in the *nature of the physical agencies* which are assumed to have accomplished geological revolutions—for there is little difference, in this respect, between Playfair and Leibnitz, Lyell and De Beaumont—but in the *measure of intensity* assigned to them in different geological periods. In both, the same laws of material action are invoked, the same causes are recognised in their effects; in both, the combinations among these causes are admitted to vary locally and periodically; both contemplate periods of immense duration as necessary for the production of observed phenomena. But in one, the Leibnitzian "theory," the globe is supposed to have undergone a *general* and progressive loss of interior heat; in the other, to have experienced only *local* or periodical variations of surface temperature; in one, great and general revolutions in the condition of the globe are deduced from a gradual refrigeration of its substance; in the other, general revolutions, properly speaking, have no place, but local changes, and new combinations, arise in endless succession: in one, the mechanical, chemical, and vital phenomena must necessarily proceed with an entirely different rate of progress, in different geological periods, because the powerful influence of heat was continually changing; in the other, these phenomena exhibit an undeviating general uniformity, such that "equal effects are produced in equal times." Taken on a great scale, time, in arithmetical series, is the element of a cycle of variations in one hypothesis; the product of time and force (one increasing as the other decreases in geometrical series) is the principle of continual progression in the other.

To enter fully into the consideration of these rival hypotheses would be at present fruitless; but we may try their power and truth on some of the more important and fundamental points in the structure of the earth, such as the actual physical geography, and the ancient climates of the globe.

Physical Geography.

Distribution of Land and Sea.

No truth is more certain or important in geological reasoning than the formation of all our continents and islands by causes acting below the sea. As far as relates to the stratified rocks this is obvious; but it is not the less certain for the unstratified rocks, these having undoubtedly been uplifted to our view from beneath the strata. It is *possible* there may yet be found *some* granitic rocks which were raised above the general spherical surface before the production of *any* deposits from water, and which may therefore be presumed to form an exception to this general rule; but such truly "primitive" rocks have nowhere been seen, nor is there any ground of expectation that they will be discovered. The elevation of the dry land out of the sea is therefore one of the great truths to which we must compare general speculations; and it affords a test, and prescribes conditions, which no false "theory" can fulfil.

The actual distribution of land and sea is very remarkable. London being taken as the centre of a hemisphere, nearly all the land is included therein. The antipodal hemisphere includes a vast abundance of small islands; but there are no considerable antipodal surfaces of land, except where Chili and Patagonia oppose the eastern part of China, and the volcanic islands of Sumatra, &c., oppose the volcanic mountains of Quito. The continent of Australia is opposite to the deep centre of the Atlantic Ocean. Only $\frac{1}{27}$th part of the present continents and islands has land opposed to it.*

The *meridian* of least land (about 16° W. long.) passes by Kamschatka, the east side of Hecla, the west coast of Africa (near Madeira, Teneriffe, the Cape de Verde islands), the west side of New Caledonia, and

* Gardner, in Geol. Proceedings, 1833.

near the west side of New Zealand. On this line it is nearly all sea. The distribution of land and water presents little symmetry; yet a meridian at right angles to that above noticed leaves, east and west of it, nearly equal masses of land. The poles are believed to be situated in the midst of extensive oceans, though the progress of modern research has augmented our knowledge of antarctic land. These circumstances, though they indicate little of symmetry in the rugged and irregular surface of the globe, supply some points not unimportant. The general spheroidal figure of the earth is obviously not the result of superficial waste and minute arrangements, as the hypothesis of the invariability of natural forces would seem to require; on the contrary, this figure appears clearly due to the general conditions of the interior masses, which are only marked and rendered irregular by the changes that have happened at the surface. Upon the Leibnitzian supposition, that the crust of the globe is cooled over an ignited nucleus, which is still further undergoing refrigeration, it appears possible to understand the accumulation of water about the poles, since, in the direction of the polar diameter, the contraction of bulk would be in no degree balanced by the augmented centrifugal force, corresponding to a *determinate velocity* and *a diminished diameter*. But, on the supposition of the spheroidal earth having been originally a sphere, and having derived its actual figure from superficial processes, the polar regions *should have been very elevated land*, and the equatorial zone deep sea. This neither is, nor appears to have been, the case.

Again, the remarkable contrast of a hemisphere of land opposing one of sea marks very clearly the influence of some great and general alterations of surface level. The supposition of a cooling globe undoubtedly meets this case; but it appears difficult to see how the rival speculation can be applied to phenomena on so vast a scale, even if unlimited time be given to the operation of "modern causes."

Heights and Depths.

The elevations on the land rise at most to about five miles above the level of the sea; and the depths of the Atlantic may perhaps be justly estimated at nine miles, from the data furnished in Mr. Whewell's Essays on Cotidal Lines.* The labour would probably not be wasted which should be given to a careful estimate of the mass of the sea, as compared with the mass of land raised above its surface; on the hypothesis of a gradual refrigeration of the globe, it is perhaps not impossible to determine by calculation the relation of these masses; and from a comparison of these independent results there would arise an important test of the truth of the speculation. The heights and depths of the land and sea appear to require the supposition of co-extensive upward and downward movements, and, as Mr. Lyell has shown, it is probable the depressions exceeded the elevations. These effects appear unintelligible, except upon the admission of subterranean surfaces of melted rock, capable of yielding to subsidence inward, and eruptive forces outwards.

But this conclusion becomes more decided when we take into account the continuity of mountain chains and oceanic depths, the abrupt borders of the sea-coasts, the large areas of tertiary and secondary strata which were formed in the old sea bed, and are now raised, with *little mark of local violence,* into almost boundless plains and vales, within a border of bold mountains. All these circumstances are the natural consequences of *extensive depression* of the crust of the globe, followed by *elevations;* both being determined in greater intensity to points, lines, and areas of weakness, in a solid crust above a fluid of small compressibility, like melted rock.

* Phil. Transactions, 1833.

Displacements of Stratified Rocks.

The notices in a former chapter (Vol. I.) will probably suffice to satisfy the inquirer after geological truth, that the elevation of stratified rocks to their present height above the sea is not merely relative, not merely caused by great depressions of the earth's surface elsewhere, but, in part at least, dependent on a *real uplifting* of mountain chains and other groups of dislocated strata. The most obvious argument in support of this is the well-known fact, that, in approaching the mountains, three orders of phenomena rise together to importance; the *inclination* of the strata becomes more and more decided and violent, till they appear vertical or even reversed; the *marks* of *violent* displacement augment in a corresponding degree; and the exhibition of *igneous* rocks becomes continually more frequent among the fractured and contorted strata. Now, if the mountain lines and groups had been *points of rest*, while all the spaces round them sank, something like the present distribution of land and sea would have appeared, but these signs of violent displacement would not have predominated in the vicinity of the mountains. There is no doubt, therefore, that these have been local centres of violence and not of rest.

The elevation of mountains has been too much regarded in the light of an insulated phenomenon: Mr. Darwin has truly pointed out its relation to *continental elevation*, which may be regarded as the great effect of a general cause manifesting itself at particular points in greater intensity. Just as, in experimental pressures, on solids of every form, the weakest part alone yields to a force which, up to a certain point, was borne equally by all, we may easily conceive a *general continental elevation* to a certain point, but beyond this, a partial rupture and relief of the pressure along a particular fissure. This is Mr. Darwin's view of the phenomena of uplifted land in and on either side of the Andes.

The same eminent observer has applied the same consideration of extensive displacements of land and sea to explain the alternate bands of elevation and subsidence, which are inferred from his survey of modern coralligenous reefs and islands. (See Vol. I. p. 336.) In this generalisation it appears that the points of volcanic *eruption* all fall on *bands* of general elevation, where the uplifting force is at a maximum. Volcanic action might thus suggest itself as the local cause of this local maximum of elevation, did we not know that exactly the same relation of continental and mountain elevation obtains for areas of land and groups of mountains where no volcanic eruptions have happened. (Nevertheless, it is not to be denied, that the effect of volcanos is, generally, to augment the inequalities of level of the earth's surface.) If this view of Mr. Darwin be well established, it will go far to confirm the general probability of a refrigerating globe; for movements of such regularity and extent require a corresponding slowly and powerfully acting cause, such as a general change of temperature must be acknowledged to be. "A change of the form of the interior fluid surface of the globe," as Mr. Darwin very correctly expresses the general condition on which all these phenomena of simultaneous elevation and subsidence may be made to depend, is a result strictly deducible from the hypothesis of a refrigerating globe; and the interesting examples of gradual and prolonged elevation in Scandinavia, and perhaps of subsidence in Greenland, appear natural and obvious consequences of that doctrine, while more violent upward and downward movements in other parts of the globe are not at all opposed to it.

The elevation of mountains is, in the doctrine of refrigeration, a local, critical, and more or less sudden result of a general and gradually accumulated force; the contrary hypothesis supposes a vast multitude of minor movements, such as earthquakes, which now happen in volcanic regions; and that these successively contribute their effects in one direction. The *magnitude* of *single* movements of the stratified rocks thus becomes a criterion of importance in estimating the value of these contrary views.

Anticlinal axes, such as that of Snowdonia, great faults, like that of the Penine chain, will perhaps be easily acknowledged to be absolutely unparalleled in historic periods; but this inequality of mere magnitude will not furnish a shadow of evidence against the application of the doctrine of the sufficiency of modern causes, unless it be proved, or shown to be probable, that the chain of Snowdon, and the ridge of the English Apennines, were thrown up by one, or, at most, a few efforts. Now this is *probable* in each case, for reasons based on observation, and, as will hereafter appear, not improbable for reasons founded in mechanical science.

Observation detects on the line of these great movements of the earth's crust no trace of the minutely confused and fragmentary condition of the strata, which must have been the result of an indefinite number of small convulsions, like those of the Chilian earthquakes in 1822 and 1835, when the ground rose convulsively a few feet; on the contrary, the simplicity and completeness of the anticlinals of Snowdon and the Isle of Wight, and the violent single fracture and few bold contortions on the Penine fault (which ranges for above a hundred miles, and may possibly extend much farther), speak of one or a few powerful efforts. This is so much the more to be trusted, as the effect of the friction on the surfaces of motion has the same character of simplicity. The area uplifted by the Penine fault may be roughly estimated at 2000 square miles; and the vertical extent of the movement may be taken, on the average, at 2000 feet. The Chilian earthquake, even if the ground were uplifted 4 feet for 100,000 square miles (neither of which assumptions seems at all supported by the narratives which are published *,) would yield, at most, only $\frac{1}{10}$th part of this mass of land.

* See p. 241. On the subject of the Chilian earthquakes, consult, generally, the Geological Society Proceedings, vols. i. and ii.

Direction.

The direction of anticlinal lines and other great dislocations of the strata has become of importance in a theoretical point of view, ever since Humboldt, Von Buch, and De Beaumont, strove to link these features of physical geography with particular epochs of geological time. If the parallelism of the Carnarvonshire and Radnorshire axes of movement is an indication of their being contemporaneous — and this analogy and conclusion can be extended to the primary slates of Cumberland, the Lammermuir, Isle of Man, and Grampian mountains — the inferences justly drawn from one district, as to the mechanism of its elevation, become confirmed in a very exalted degree. It is, therefore, most important to inquire, not merely what foundation there may be for the particular system on this head, which is supported by the learning and talent of De Beaumont*, but further, within what limits observation or mechanical science allow us to consider it possible to determine the geographical extent of contemporaneous disturbances of the strata.

The propositions of M. De Beaumont, in their utmost extent, may be thus understood. The principal dislocations of the same geological age range in lines parallel to one and the same great circle of the sphere; those of different ages are parallel to different circles. The geological era of the elevation of mountains may be known from the direction of their axes of movement. The mode of *proof* will be understood from the following abstract relating to the system of dislocations, referred by De Beaumont to the period preceding the deposits of green sand and chalk; and the extension, by analogies, from a limited proof to a large range of probabilities, will appear in the short notice of two other systems of later date.

Three small granite eminences, in the Côte d'Or, near Sombernon, which have occasioned the disruption

* In Ann. des Sciences Naturelles for 1829—30.

of Jura limestone there, range in a line N.E. and S.W. parallel to the summit ridge of the Côte d'Or. The line of these granite points being considered part of a geodesical circle, and prolonged in each direction, is found to coincide with several remarkable geological accidents or disturbances. In the N. E., for instance, it coincides with dolomitic oolite and steep dips at Sury, between Langres and Dijon; with the hot springs and magnesian muschelkalk of Bourbonne les Bains; with the basaltic eminence of Essey, of Luneville, and with the granitic protuberance of Albersweiler, between Annweiler and Landau.

Another line of disturbance, parallel to the preceding, is indicated; and it is observed that from Paray (Saone et Loire) to Plombières (Vosges), the great line of valley watered by the Bourbonne and Saone is perfectly parallel. This line, prolonged into Germany, passes along the valleys of the Mayn and the Saal, through Mittenberg to Leipzig, and is parallel to the Erzegebirge and Mittelgebirge.

Now all these dislocations were probably produced at the same geological epoch; which, though inferred from the general phenomena along the line, is determined more exactly in consequence of an extension of this system of faults by a series of parallels retiring to the S. E., till we arrive in the department of the Rhone, where the chalk and Jura limestones are *found together* — the latter dislocated, the former undisturbed. The direction of this *line of disruption* is N.E. and S.W. at Dijon.

In the Jura, a great number of undulations in the strata range parallel to a line N. 40° E., or N. 45° E.; and, being sometimes filled with green sand deposits, are clearly of the same date as the above disruptions.

In abstracting the proofs of the other grand systems of elevations, we shall attend less to the minute than to the general analogies. The insulated chain of the Pyrenees, one of the most remarkable in Europe, forms the base of the system. Many observations prove that the chalk and green sand are here uplifted with the primary rocks; but the later marine lacustrine deposits lie level upon their slopes, and were clearly deposited from a sea which washed the base of the already elevated mountains.

The general direction of the chain from Cape Ortegal in Galicia to Cape Creuss in Catalonia, is a little south of east; but this general chain is composed of partial ridges, whose axes are parallel to one another, and directed W. N. W. and E. S. E.

This direction belongs to the disturbances of the same date in Provence, and near Nice, and is recognised in the Apennines, at least in the northern part, and in the country of Naples, and along the south shore of Sicily. The south western boundary of the Nägelflue in Switzerland appears to correspond with the Pyrenæo-Apennine line; as do likewise the Dalmatian and Croatian summits, the valleys of the Save and the Drave, the line of the Rhodopian mountains, and the ridge which crosses the straits of the Bosphorus. Similar directions seem to be traceable in Greece; and, as far as the evidence yet collected goes, the date of the elevation of all these mountains may be the same. The Carpathian range, parallel to the Dniester, falls into the same system, with a small line of granitic and sienitic rocks along the Elbe near Dresden, and the mean courses of the metallic veins of the Hartz. Finally, the well-known disturbances of the strata in Sussex and Hampshire have the same age, and lie in the same parallel. Extending his views, M. De Beaumont finds some traces of the Pyrenæo-Apennine system in Africa, and Syria, in the Caucasus, and in the Ghauts of India; but the imperfect state of information concerning the geology of these countries renders the inferences concerning them far from precise.

On prolonging the Pyrenæo-Apennine circle across the Atlantic, by Hecla and Greenland, to the New World, we find it descend parallel to the Alleghanies and their northern connexions, which have determined the form of the eastern shore of the United States, and, as De Beaumont collected from the statements of transatlantic geologists, were probably uplifted between the age of the chalk and the latest of the stratified rocks.

Such remarkable accordances of epoch and linear direction, over so enormous a length upon the surface of the globe, cannot, says De Beaumont, be the result of chance, but of a regularly acting internal cause.

M. de Beaumont has entered into a minute examination of dislocations affecting the molasse, one of the most recent of the tertiary deposits. He has connected the line of these disturbances in the south of France with those which may be observed in the western Alps from the Grande Chartreuse near Grenoble to the Salève near Geneva, and in the primary chain from the mountain of Taillefer to Mont Blanc, in the direction north, 26° east. Numerous observations in the valley of the Durance, though full of discordances, are reduced by the author to the same general line north, 26° east, which agrees with the opposite escarpments of Mont Blanc and Mont Rosa, and nearly with the line of a remarkable dislocation parallel to the Jura from Molezon to Aarburg, and with the depressed region occupied by the Lungern See, Sarner See, Alpnach, Kussnacht, and the lower parts of the lakes of Zug, Zurich, and Constance. The volcanic cone of Hohentwiel, beyond Schaffhausen, being upon the same line, gives occasion for the remark, that a system of disruption of the same age has thus been traced in one direction for above 100 leagues.

In the prolongation of this line to Nova Zembla, no instance is mentioned of corresponding disruptions; but the long Scandinavian Alps, and particularly the Dovrefeld Mountains, are parallel to it; and it was in consequence of their elevation that so large a quantity of Norwegian rocks have been scattered over northern Europe: the late date of this dispersion of blocks proves the late date of the elevation of these mountains.

Some traces are supposed to be found in Africa of the same line of disturbance, and even the chain of the south-east coast of Brazil, from Cape Roque to the Plata, though 400 leagues distant from the great circle of Zurich and Marseilles, might, perhaps, upon this hypothesis, be referred to the same epoch.

The most striking difficulty to the reception, at present, of any hypothetical connections between geographical lines and the irregular lines of disruption of strata, arises from the excessive number of these disturbances, and the variety of their directions. Brongniart has expressed, in strong terms, his impression on this subject, by saying that there is hardly a square myriameter of the earth's surface which has been left in its original position.

This difficulty, however, would only perplex the observer, not obscure the reasoning. There is another of more importance. The exact geological date of a dislocation of strata is very difficult to determine, and in most cases is merely known within wide limits. Who can *prove* the contemporaneity of the elevation of Snowdonia and the Grampians, when the strata dislocated are not the same, and the covering deposits are different? In the north of England the rothetodteliegende and magnesian limestone cover dislocated coal; in some parts of the south of England they are not traceable. The dislocations of the coal *may be* of the same age in both districts, but it is impossible to prove it.

These are difficulties in the examination of De Beaumont's views, not objections to their truth. There is, apparently, only one mode of discussion which is likely to be at all satisfactory: we may compare together the directions of dislocations, which are probably of the *same* geological period, and afterwards some of those which are known to belong to *different* periods.

The first class of dislocations, which, in this vague sense, may be called contemporaneous, belongs to the period anterior to the whole carboniferous and old red sandstone series of rocks. To this period the anticlinal axes of the Highlands and Lammermuirs, prolonged to Donegal and Cavan, the Cumbrian mountains, the Isle of Man, and North Wales belong. Now all these axes of elevation range north-east and south-west, and thus appear to support De Beaumont's hypothesis. Professor Sedgwick, in a recent communication to the Geological Society (May, 1838), speaks of the importance of attending to this conformity of direction in the axes of elevation, while attempting to join into one classification, according to geological age, the formations of distinct regions. He states further, in support of the same general views, the probable contemporaneity of the parts of another and later system of dislocations passing *east and west* in Cornwall, Devon, and South Wales, after the deposition of the coal strata. Lastly, he notices a system of dislocations which have brought up a portion of primary rocks, at Dudley, on both sides of the Coventry coalfield, and in Charnwood forest. At all these localities the "strike" is the same, and the lines of the greatest movement are nearly parallel, all being about N.N.W. and S.S.E.; and all these movements belong to one epoch, having been completed after the deposition of the lower new red sandstone (rothetodteliegende), and before the period of the upper sandstone and gypseous marls. Hence we have three great systems of elevation, which occurred during three distinct geological periods, and range in three distinct geographical directions.

This favourable testimony to the hypothesis of De Beaumont might perhaps be further extended: it is, however, met by the following facts: —

Dislocations almost perfectly parallel to those of Devonshire and South Wales range across the cretaceous and tertiary systems of Hampshire, Dorsetshire, and Sussex. In the counties of Radnor and Brecon, anticlinal axes range N.E. and S.W. through districts where the old red sandstone is conformed to the primary strata; and the same direction is observed extensively in the south-western part of Yorkshire, in anteclinals which cross the upper part of the mountain limestone series.

Here, then, dislocations of very different ages appear conformed in direction to some that have been mentioned before.

With such uncertainty in the data for reasoning and such contrariety and complexity in their indications, it is obvious that no definite and satisfactory conclusion can be at present adopted on the question of the parallelism of mountain elevations which belong to one geological age.

The great ranges of mountains, &c. marking the dislocations of the strata, cannot at present be accommodated to the strictness of a general geographical system ; it is, however, not the less desirable to examine the same question on a smaller scale, with the aid of mechanical science and rigorous observations.

The well-established facts of the local parallelism of particular classes of mineral veins, already put in evidence in a preceding chapter, leave no doubt of the existence of some real symmetry of the systems of dislocation in every limited district. In several instances approximate parallelism has been observed between mineral veins and the numerous divisional planes of stratified rocks ; and in others a peculiar dependence has been traced between the direction of a vein-fissure and that of an axis of elevated strata. Phenomena of this nature would for ever remain unexplained, if mathematical methods of research could not be applied to them ; nor can they be applied except upon certain assumed conditions of mechanical action.

The first step in this career of discovery has been taken by Mr. Hopkins, whose memoir in the Cambridge Philosophical Transactions is remarkable for the simplicity and probability of its fundamental postulates, and the ready applicability of its conclusions to the results of observation. That the crust of the earth is elastic and capable of extension, earthquakes demonstrate ; that cavities exist below parts of it is certain ; and that these have a considerable horizontal extent is probable. There is no room for doubt that similar conditions existed in early geological times ; for such cavities below the earth's crust would probably arise either from general refrigeration of the globe, or from local variation of heat. In such cavities the accumulation of elastic vapours is almost a necessary consequence, and it is conceivable that the crust of the globe would in parts yield to their force.

But Mr. Hopkins's reasoning would be in no degree invalidated, if for this mechanism of elastic vapours and cavities, an outward pressure derived from some other cause were hypothetically substituted, provided only that the area of its operation were sufficiently large, and its force *continuously augmented* until the earth's crust broke with the accumulated strain. The direction of the fissure at the instant of fracture can be determined mathematically, whether the intensity of the elevatory force be uniform at every point of the surface, or greater at particular points; provided the boundaries of the surface and the resistance offered by the cohesive power of the mass raised and broken be known. This last condition, indeed, does not require to be very precisely fulfilled, except in a horizontal direction; for in a vertical plane, the cohesive power may vary according to any discontinuous law, as must happen in every series of dissimilar strata. (The pre-existence of joints in the rocks raised offers greater difficulty; but as few of these traverse great masses of rock, and each stratum has some peculiarity in the distribution of the joints, it does not appear to us *necessary* to except even this case.)

The following are among the results of the investigation when applied to a case resembling the actual condition of the stratified crust of the globe.

1. *Production of longitudinal fissures.* — If the mass of ground raised by an elevatory force of uniform intensity be of indefinite length, and bounded laterally by two parallel lines, the extension and therefore the tension at any point will be in a direction perpendicular to the length; and the line of fracture will necessarily cross this direction, so that fissures cannot be produced under these circumstances, except in a longitudinal di-

rection, or parallel to what may be called the axis of elevation. It appears that these fissures will not commence at the surface, but at some lower part of the mass. The whole series of stratified masses will be affected by the tension in the same manner, but under some conditions the fissures may not reach to the surface. The fissures will be of nearly uniform width at all depths, except that unequal elasticity in the dislocated strata will cause some differences. It is not inconsistent with mechanical principles to admit that more than one parallel fissure may originate simultaneously, and they may be subsequently prolonged, so that many parallel fissures (especially below the surface) may exist together, the fruit of one general action. No sooner, however, are the fissures extensively formed than new conditions arise, and any further fracture can be produced only in new directions. Wherever such a system of parallel fissures is found to exist in the same mass of strata, it is physically impossible that they can have originated at considerably different times, though the prolongation of a fissure may have been effected long after its origin.

2. *Formation of transverse fissures.* — In a district, circumstanced as stated, the application of any further force would cause extension of the now free parallel parts of the mass only in the direction of their length, and consequently produce ruptures at right angles to the former fissures. One or more of these transverse fissures might in like manner be produced in each of the parallel bands of displaced strata. In any country which manifests two systems of parallel fissures, one at right angles to the other, it is absolutely certain that the effects are due to no more than one general elevatory force, and one continuous effect for each system of parallels; a series of partial forces at particular points or different times could not produce the effects.

3. *Formation of fissures in a conical elevation.* — If the mass of strata moved offer a uniform resistance, a conical elevation of a part can only be occasioned by

forces of great intensity determined to a limited area. Fissures will in this case be formed so as to pass through the axis and radiate from the centre of the cone, as is observed to be the case in the Plomb du Cantal. If in addition to a general elevatory force, supposed to act in the production of longitudinal fissures, a partial force was simultaneously acting at a particular point, the fissures would deviate from parallelism to approach that point. An instance of this was observed by Hopkins, in connection with a limited elevation of millstone grit, through the coal strata of Derbyshire.

4. *Faults.*—The masses thus separated by fissures might, upon the weakening of the elevatory force, fall back in some confusion, so as to occasion *faults* of different kinds.

We shall only observe further on this subject, that a circumstance of importance in determining the direction of the lines of fissure is the weighting of the masses, which for many reasons must be supposed to have been often very unequal. The more general the mechanical agency, and the more uniform the resistance of the masses, so much the more perfectly straight and parallel the systems of simultaneous and successive fissures.

The conclusions thus obtained seem to apply with special accuracy to the veins and cross courses of Cornwall, Brittany, Cumberland, and Northumberland, the Hartz, the Erzgebirge, and other districts, and assist very much to strengthen the conviction derived from other phenomena, that the great faults and other forms of disturbance may have been occasioned by single continuous efforts of general subterranean forces. If so, it is difficult to believe they can have been due to such effects as those made by modern earthquakes.

Periods of Ordinary and Critical Action.

Whatever may be the fate of De Beaumont's speculation regarding the elevation of mountain groups, at particular geological æras, and in certain geographical parallels, the investigations to which it has conducted are likely to have an important and permanent influence on geological observation and theory. Already, in the countries best examined,—in England, France, Germany, in Europe generally, and in North America, it is found possible to determine one or more periods when great and extensive subterranean pressures broke the submarine crust of the earth, and raised particular tracts of land above the reach of further marine deposits. Comparatively short periods of widely extended disturbance in the equilibrium of heat are thus clearly established, in alternation with far longer periods of repose in the same regions; and though it may be rather a coincident than a dependent phenomenon, it is not to be doubted that, among the older strata, these critical periods of disturbed equilibrium of heat correspond to critical periods in the revolutions of organic life. That either of these results is true *universally* would be a ridiculous affirmation, in the present state of our ignorance concerning immense areas of the globe; but it will not be the less useful to exemplify their truths, chiefly by application to the British islands. The following table is intended for this purpose, and may be compared with that on page 152., which contains some of the same elements: —

Primary period, of ordinary action, among the aqueous and igneous agencies; the ancient bed of the sea was filled with sediments, the most recent of which obviously were derived from tracts of land, which are now for the most part submerged. The organic remains of this whole period really compose but one series, in the same sense that the fossils of the oolitic or cretaceous system are one varied group. There were local disturbances of the sea bed in the Cumbrian and other districts.

An interval of dislocations followed, in which all the primary strata of England, in every part (excepting perhaps the silurian region), were raised to angular positions, so that the next system rests unconformedly upon them.

Carboniferous period, of ordinary action; the sea filled with new sediments by inundations from the land which had been lately and previously uplifted. The series of organic remains undergoes an entire and apparently sudden change of species.

Another interval of dislocations, so general and remarkable, that there is not a coal field in Europe which appears to have been exempt from them. The geological date is not always assignable, except within the limits of the uppermost coal deposits, and the base of the new red sandstone. The whole period of rotheliegende and magnesian limestones may be included in this interval, and some of the peculiarities of the saliferous system are probably the effects of this great disturbance.

The oolitic and cretaceous periods appear to have been scarcely broken by any *violence* in the region of the British isles, but the whole bed of the sea underwent a gradual and continual rise, which brought up progressively the north-western parts of the oolitic rocks. (On the continent of Europe the oolitic and cretaceous periods were divided by an interval of great disturbance.)

An interval of extensive dislocations has been recognised by M. de Beaumont and others, under the title of the Pyreneo-Apennine system; in England the *effects* of disturbance are chiefly exemplified in the conglomerates and pebbles which abound in the lower tertiary strata.

The eocene period of Mr. Lyell succeeds, with a prodigious number of organic forms, almost wholly distinct from those of the older strata.

The dislocations of the western and eastern Alps, combined with the evidence afforded by diluvial phenomena and raised sea breaches in many parts of the world, appear to show a separation between the eocene and modern periods by a *period* of violent disturbances, connected with the rising of some of the highest mountain ranges in the world. The conjecture of De Beaumont, that the elevation of the Andes was one of the latest of these great disturbances, has been verified by the researches of Mr. Charles Darwin in Patagonia and Chili. (*Geol. Proceedings.*)

Modern Period of Ordinary Action.

The value of such an arrangement as that here presented is not in its minute accuracy, but its general application; and in this respect it is, apparently, worthy of considerable confidence. It is however impossible to assert, or to believe, that the *intervals* of disturbance were *very* short, or that a mountain range rose in a moment, to divide an ocean and change the relations of organic life. The alternation of great periods of repose and disturbance, in every district yet examined, is certain; the correspondence of these periods in remote regions, though not completely proved, is rendered probable; and it only remains to see what is the bearing of this discussion upon geological theory.

Such alternations of repose and violence appear a necessary consequence of the gradual refrigeration of the globe; the duration of repose and the violence of the disturbance being dependent on the resistance to pressure offered by the consolidated crust of the earth. However hot a planet may have been, it is conceivable that in time sufficiently long the radiation of its heat into the cold ethereal spaces must continually reduce its internal temperature. The solidified crust, when cooled to the temperature derived from the joint influence of the hot sun and the cold regions around the globe, suffers no further loss of heat; but the internal parts may still grow cooler through immense periods of time; they may thus contract more than the outer parts, and fail to sustain them; fractures follow, and the equilibrium of pressure is restored, till a long period of cooling revives the irregularity of forces, and the crust breaks again. Periods of ordinary, and intervals of critical, action are direct consequences of the Leibnitzian doctrine.

This however does not prevent the favourers of the contrary hypothesis from adding to their speculation of the constancy of natural forces the further assumption that they are subject to a cycle of large variations, such as those "perturbations" which affect even the regular orbits of the planets. Such cycles of variation have been *suggested*, but unless a *cause* be assigned (as is done for the planetary perturbations), this gratuitous addition of one hypothesis to another weakens the probability of both. This appears to us an impartial view of the subject.

Climate.

That during early geological periods, the northern zones of the earth enjoyed a climate approaching to that which is now confined to the equatorial regions, is admitted among the established inferences of geology, upon the evidence of the remains of plants and animals found imbedded in the strata. For reasoning on this subject which we deem satisfactory, the reader may consult a former chapter of this work. (Vol. I. ch. v.) A true geological theory must be capable of fully accounting for the change of temperature which has thus affected large regions of the globe.

Besides the general speculation of a refrigerating globe, we have on this subject three others to examine. The hypothesis advanced by Mr. Lyell is founded on the acknowledged fact that the mean temperature of any point on the earth's surface is liable to considerable variation, according to the position of land and sea. By supposing a peculiar distribution of masses of land, equal in area and elevation to the present continents and islands, this eminent author endeavours to account for the facts regarding ancient climate, without calling in aid any external or internal sources of a change of heat.

There are, however, two external sources of change of the mean temperature of the whole globe. The calorific influence of the sun may increase or diminish, because the mean distance of the earth from that luminary is subject to variation: the temperature of the ethereal spaces in which suns and planets move may not be the same in every part; and, if the whole solar system has a movement of translation in space, it is possible that in some former period the earth may have passed through regions of the universe which communicated heat instead of abstracting it.

We shall first notice the speculations which relate to external sources of heat and cold.

The variability of solar heat, as bearing on geological problems, has been investigated by Sir John Herschel. It is known that the major axis of the earth's orbit is invariable, but that the minor axis is subject to considerable change in a long period of time, though the *limits* of the *variation* of excentricity which this produces in the earth's orbit are unascertained. This excentricity is at present, and has been for ages beyond the reach of history, on the decrease, because the minor axis of the earth's elliptic orbit is continually lengthening. The limit of this elongation is now nearly reached, for the orbit has become nearly circular.

It must be very obvious that the amount of solar heat received on the earth (the major axis of the orbit being constant) diminishes as the minor axis is elongated, and, therefore, the earth's heat derived from the sun has been through all historic time, and is at this moment, *on the decrease.* The quantity of solar heat received on the earth, is, in fact, inversely proportional to the length of the minor axis of the orbit; and were the limits of the variation of this axis calculated (which would be excessively laborious), the extreme change of climate from this cause might be known. Taking, however, the extreme measures of excentricity, which occur in our planetary system (Juno and Pallas for example), as *possible* in the case of the earth, Sir J. Herschel deduces from calculation that the utmost difference of mean solar radiation might amount to about three per cent., a quantity certainly very small, and altogether inadequate, except by a peculiar combination of favourable circumstances, to account for the changes of climates established by geological observations. Until the calculation alluded to be actually made, it appears unreasonable to attach much weight to this source of variation in climate.* The solar heat annually poured upon the earth is stated by Pouillet to be sufficient to melt a coat of ice 14 metres thick, encrusting the whole globe of the earth.

2. The heat of the planetary spaces is a subject on which, Mr. Whewell justly observes, the scientific world has hardly yet had time to form a sage and stable opinion. Fourier has asserted the existence of a definite temperature in these spaces, and ascribes it to the radiation of the fixed stars in every part of the universe. He assumed this temperature at about 50° centigrade below the freezing point, and Swanberg has been led, by a wholly different line of reasoning, to nearly the same result, as to the degree of temperature of the void spaces of our system.

This view of the state of the ethereal spaces is important in the application of the mathematical theory of heat to the present and former conditions of the earth. But M. Poisson, while fully admitting the existence of considerable heat below the surface of the earth, and the comparative cold of the spaces which now surround our globe, assigns the following reason for the high temperature below the surface. The cosmical regions in which the solar system moves have a proper temperature of their own, and this temperature may be different in different parts of the universe. The earth, in whatever part of these spaces it be placed, must be some time in acquiring the temperature of that region, and this temperature will be propagated gradually from the surface to the interior parts. Hence, if the solar system moves out of a hotter into a colder region of space, the part of the earth below the surface will exhibit traces of that higher temperature, which it had before acquired. Thus, without supposing great heat in the whole mass of the interior parts of the earth, the phenomenon of

* See Geol. Trans., 2nd series, vol. iii.; and Geol. Proceedings, vol. i. p. 245.

augmenting temperature below the surface would be explained.*

Geologists will probably be pardoned for not attaching importance to this remarkable speculation, except for the proof it affords that men of enlarged conceptions, and the highest mathematical endowments, regard the facts already known by observation of the heat now present within, and the climate which anciently overspread the earth, as inexplicable, except by general variation of heat through a considerable part of the mass of the earth, or even a great range of the cosmical regions. Local sources of heat are deemed inadequate, and left unnoticed by Poisson, Fourier, Arago, and Herschel.

We have therefore finally to compare the account of the changes of ancient climate, proposed by the distinguished advocate of "modern causes," for comparison with that furnished by "refrigeration of the globe."

The principle of Mr. Lyell's hypothesis of changes of climate, in different geological periods, is the change of position of the land. We have already stated as a main cause of the differences of the mean annual heat at places which lie in the same zone of latitude, and consequently receive the same quantity of solar radiation, the *influence of oceanic currents.* The tides raised in the equatorial seas circulate round the globe, and, by spreading up the North Atlantic and North Pacific communicate warmth to the western shores of Europe and America. Oceanic currents, arising from other causes, mix the temperature of different latitudes, and moderate the extremes of heat and cold. Nor is this all. The higher that land is raised into the atmosphere the colder does it become, and the larger the mass of this elevated land the more powerful is its cooling influence on the vicinity. For this reason, the mean temperature of North America and Northern Asia is generally much lower than that of Europe in the same latitudes.

* See Mr. Whewell's Report and Communications to the British Association, 1835.

The nearly meridional band, which has the highest mean temperatures on given latitudes, passes up the Atlantic, along the west coast of Europe. In latitudes below 30°, the difference between the temperatures on this line of greatest heat, and those of America and Asia, though perhaps always sensible, is slight; but on arriving in high latitudes, the contrast is somewhat startling. Upsal, in latitude 60° N., has about the same mean temperature (42°) as Quebec, in lat. 47°. The isothermal line of 32° crosses the North Cape in lat. 70°, and from this vertex of curvature descends southward by the south side of Iceland, and the south part of Greenland, to the north point of Labrador, almost to lat. 60°. This is the most southerly part of the curve, which then bends to the north, and reaches 65° at Great Bear Lake, beyond which its course has not been completely traced. In the other direction, from the North Cape, this line deviates to the south, till it crosses the Lena below lat. 65°. Thus on the line of 32° it rises in the meridian of Norway 10° of lat. further north than in America, and 5° further north than in Asia. Nearly similar results follow from tracing the other isothermal lines determined by Humboldt in high northern latitudes, but the difference above stated is more than the average. In the same latitudes, Europe is warmer than North America by 5° Fahr. or more, but in particular situations this difference is much greater, amounting, in extreme cases, to 11°, or even to 17°. Such uncommon differences, however, are unimportant in a general argument.

Some portion of the great difference of the Atlantic and the continental climates may safely be ascribed to the gulf stream, which carries the warmth of Guinea even to Spitzbergen (according to Scoresby); but without this aid, a deep polar ocean communicating to equatorial seas must always mitigate the cold of the Arctic zone along the main channel of connexion, as a mass of Arctic land lowers the mean annual heat of the temperate zones, by collecting an eternal covering of snow and ice. On the contrary, in both respects, land in the equatorial regions may absorb more heat than water; and thus we have, as general conclusions, the *greatest uniformity* of climate, with the greatest expansion of sea; the *greatest mean annual heat* toward the poles, with equatorial land and polar oceans; and the *least mean annual heat* with polar land and broad equatorial sea.

If, therefore, during one long geological period, land of the same extent as that now above the waves, and rising to the same height, were situated round the poles, while the zones of the earth, which received most solar rays, were occupied by sea, there can be no doubt that the mean annual heat of the whole terraqueous surface might fall considerably, the greatest depression being in the polar regions. Such a state of things is fancifully called by Mr. Lyell the *winter of the "great year."* On the contrary, with continents equal to the present placed on the equator, and wide oceans overflowing either pole, there would be an augmentation of mean annual heat, and the "summer" of the great year would have returned!

Several questions, however, remain to be answered, before this elegant hypothesis can be embraced as a sufficient cause of the changes of climate, which appears to have come over the northern zones.

The collecting of land around the poles, or on the equatorial line, or in any other position, is not positively contradicted by known geological facts, but neither is any decided support given to the assumption by those facts: it cannot even be declared to be *probable* or *improbable*, on the ground of observations; for though these certainly teach us that the position of land and sea is indefinitely variable, they have determined little or nothing concerning their actual distribution in former geological periods.

This speculation is then purely hypothetical, and framed to suit the phenomena, as others may be, and have been; but it involves no physical improbability on a great scale, and its details are based on real causes.

We may, therefore, inquire farther, whether it is *sufficient* to explain the facts admitted concerning ancient climate. If we take the oceanic polyparia, which abound in reefs among primary and carboniferous strata, as a mark of climate not inferior to that of the coolest regions where now coral reefs are formed, the mean temperature of the sea in the latitude of Christiania, situated on what is now the *warmest band passing across the isothermal lines* (now about 43°), must have been about 20° F. higher, which, added to the already existing excess of temperature on this line above the average, makes nearly 30° F. for the necessary augmentation of *marine* temperature toward the north pole.

On the land, a very similar augmentation of temperature must be supposed: for the evidence of the arborescent ferns and fluviatile reptilia goes very much to establish the necessity of a mean temperature of above 60°, wherever the coal deposits spread in great abundance. Taking the coalfield of Edinburgh as an example, the mean temperature of the ancient land which supplied the plants there buried and changed to coal, may have been about 15° hotter than now occurs on this warm meridional band. It may, indeed, be *supposed* that these plants were drifted from southern lands; but what is the inference from observation? It is exactly the *contrary*, according to the evidence furnished in the *Illustrations of the Geology of Yorkshire;* where both for the oolitic and the earlier coal strata, it is proved that the drifting was *from the north.*

Surely these are serious obstacles to the reception of the hypothesis of change of ancient climate, by altered position of land and sea, on the ground of its being *sufficient* to meet the phenomena. In general, perhaps, we may venture to remark that it is unsafe to push the opinion of the possible *average* change of temperature in extra-tropical regions, beyond the EXTREMES now observed therein. America, with little north tropical and wide north polar land, gives us a case of extreme refrigeration from the pole toward the equator; Africa and the west of Europe compose a surface of wide and hot north tropical land, with free channels to a polar sea. The *extreme difference of these extreme climates* does not, we believe, in any two points of like elevation reach 20°, the half of which is, perhaps, more than the *extreme excess or defect of heat* beyond the average of the latitude at any one point upon the surface of the earth.

If an *average* excess of 10° of temperature be allowable according to this hypothesis, the *extreme* excesses may have been somewhat greater; but from the conditions of the hypothesis they cannot be taken to be so great as the extreme excesses now observed on the globe, but must be supposed comparatively small.

We have, therefore, only further to inquire in what manner the doctrine of *progressive refrigeration* of the globe from the earliest periods meets this case of the change of climate in regions far from the equator. Some geologists appear to have adopted, on the subject of the earth's interior heat, a singularly erroneous opinion; viz. that a cold solid crust and an incandescent nucleus are incompatible. The doctrine of "central heat" (as the Leibnitzian speculation is sometimes inaccurately termed,) is, upon this false notion of the conduction of heat, declared to be a *physical mistake.* Yet it can be easily shown, both by experiment and mathematical calculations, to be a *necessary truth,* in a body circumstanced as the earth really is. If one end of a bar of metal, a few feet long, be plunged in the fire, while the other end is wrapped in a wet cloth, the one end may be ignited to any desired degree, while the other can be kept at any required temperature above a certain point, depending on the heating and cooling powers applied to the ends of the bar, its length, and the conducting and radiating powers of the metal. Instead of the metal bar, submit to the same heat a bar of stone, or a rod of glass; in these cases, unless the bar be *very short,* no cooling power at all is needed further than that of conduction and radiation from the surface of the bar, because of the extreme feebleness with which heat passes through its interior parts. What is the difficulty of applying this reasoning to the stony crust of the earth?

Fourier has done this in a manner which mathematicians deem admirable and satisfactory, in his masterly '*Treatise on Heat*,' now become the standard book of reference in the highest department of this subject. We shall use the words of one who has examined the arguments of Fourier.* "Some of the results of this theory are fitted to make less formidable the idea of having a vast abyss of incandescent matter within the comparatively thin crust of earth on which man and his works are supported. It results from Fourier's analysis, that at 20,000, or 30,000 metres deep (12 to 18 miles) the earth may be actually incandescent, and yet that the effect of this fervid mass upon the temperature at the surface may be a scarcely perceptible fraction of a degree. The slowness with which any heating or cooling effect would take place through a solid crust is much greater than might be supposed. If the earth below 12 leagues depth were replaced by a globe of a temperature 500 times greater than that of boiling water, 200,000 years would be required to increase the temperature of the surface 1°. A much smaller depth would make the effect on the superficial temperature insensible for 2000 years. It is calculated, moreover, that from the rate of increase of temperature in descending, the quantity of central heat which escapes in a century through a square metre of the earth's surface would melt a column of ice having this metre for a base and 3 metres for its height."

Now it follows as a necessary consequence of the progressive refrigeration of the globe, that whatever be at this time the influence of interior heat upon the temperature of the surface, it was in early geological periods far greater than at present, and has been slowly diminishing, till, in Leibnitz's words, a consistent state

* Whewell's Report to British Association, 1835.

of things is reached*: for both theory and observation agree in showing that internal heat is almost insensible among the other elements of climate. During the last 2000 years it is calculated that the cooling of the globe has not lowered its surface temperature $\frac{1}{300}$th of a centigrade degree; for had this been the case some change in the length of the day would have become perceptible since the era of Hipparchus. This fact has sometimes been urged as an *objection* to Fourier's conclusions, though it is really a corollary from the theory, and its agreement with observation might have been, with equal justice, mentioned in corroboration of its truth.

It is very conceivable that, in the earlier stages of the cooling of the globe, a moderate general warmth of 30°, 20°, 10°, &c. might be successively communicated from the interior to the surface; and it has been already seen that this uniform addition to the effects of the solar radiation would supply in northern zones as far as 70°, 60°, 50°, 40°, &c. of latitude successively, the temperature requisite to allow of coral reefs in the sea, palms and tree ferns upon the land, and crocodiles and other huge reptiles in the rivers and estuaries.

On the whole, until the *sufficiency* of a peculiar position of land and sea, to meet the phenomena of a change of climate is *proved*, and some *independent* ground of definite *probability* is assigned for the occurrence of such a position, it would be premature to recognise in the present aspect of the hypothesis which proceeds upon that assumption the features of a *true theory*. But it would be equally unjust to condemn it as false, for it is *not disproved*, and no one has shown that such positions of land and sea as Mr. Lyell has contemplated, may not acquire a determinate *probability* among other consequences of a *general theory*. In the mean time that admirable writer has conferred no small benefit on

* "Donec quiescentibus causis, atque æquilibratis, consistentior emergeret rerum status." (See Conybeare, *Report on Geology, to British Association*, 1832.

geological theory by introducing for consideration this elegant and consistent speculation.

Conclusion.

That the doctrine of progressive cooling of the globe is to be now received as an established theory, those who desire the real progress of geology will prevent themselves from affirming; and perhaps few who have attended to the *inferences* contained in these volumes will hesitate to believe that it will one day become so. It is no small argument in favour of this hypothesis (as it must still be called), that it appears to include, easily and obviously, so many of the leading and general truths established by geological observation. The figure of the earth, its density, the actual temperature of its surface and interior parts; the general floor of igneous rocks below the strata; the repeated formation and uplifting of such rocks; the great and systematic fractures of the earth's crust; are all capable of explanation by this *one consideration.* Moreover, it assigns a reason for the remarkable uniformity and extent of the earliest as compared with the latest deposits of water; and accounts for the characteristic induration of the ancient rocks, the rarity and even total absence of organic remains in them, the changes of climate, and the periods of ordinary and critical action, which observation has established, by *one and the same principle.* The proximity of heated masses to the surface in the early ages of the world, to which these phenomena are easily referred, is indeed hardly doubtful, since it is equally indicated by a full investigation of the sources and distribution of terrestrial heat at this day.

What then is wanted to turn this apparently fortunate speculation into an established general theory? It is the same process which has given stability to the idea of gravitation, and is now employed to sustain the undulatory theory of light. It is the *deduction of cha-*

racteristic phenomena in the real order of their succession.

To this task geologists, as such, are quite unequal. The preliminary investigations in mechanical and chemical philosophy are yet incomplete; we do not *know* to what extent the earth, in its interior parts, is solid or liquid; we cannot affirm in what state of combination the substances there occur; the rate of increase of heat below the surface is only approximately determined in particular regions; the depths of the sea have not been measured; the geological surveyor has not visited above half the globe; the true relations of the existing creation of life to those which have passed away are yet the subjects of discussion; the times which have elapsed during the accomplishment of geological revolutions are not even reduced to conjecture!

Yet in spite of these disadvantages, the conviction is spreading that some good will result from even an unsuccessful attempt to deduce mathematically the main consequences of the Leibnitzian speculation. To this task Mr. Conybeare invited attention in 1831; and since that time Mr. Hopkins has given proof, in more than one Memoir, that the subject is in able hands. The mist is gradually disappearing; and if we see not clearly the high point of truth which we desire to reach, and which may yet be far distant, at least the direction of our march is found; and though the paths may be devious and hazardous, they are full of beauty and delight.

CHAP. XI.

POPULAR VIEWS AND ECONOMICAL APPLICATIONS OF GEOLOGY.

The favour with which geology has been received into the circle of modern science, is mainly attributable to its all-pervading and expanded harmony with other branches of study, with popular sources of intellectual enjoyment, and important commercial and agricultural applications. Public taste changes from time to time its objects of special attention, but not capriciously nor unjustly; and geology has been advanced rapidly during the last 10, 20, and 30 years, because its march had been previously retarded, and because in its progress all other parts of the great contemplation of nature were deeply interested. The preceding pages have given illustration of the real and mutual dependence of geology, and the parts of human study which relate to the living forms, habits, and history of plants and animals, — the energies resident in and acting among the atoms of matter — the forces which operate in the air and water above, and in the rocky depths below the surface of the earth — the constitution and phenomena of the planets, and the state of the ethereal spaces in which suns and planets move, at distances which are beyond expression and conception. Considered in these aspects, geology is a boundless study; and yet only the indolent will turn away from its allurements, since every part of its truths is full of rare and profitable results.

It is sometimes, not very fairly, objected to modern geology, that the superior accuracy and power of research which it has turned on the ancient mysteries of nature, has been purchased at the cost of the plainness and accessibility which it is imagined should attend the interpretation of phenomena so obvious as those in the crust of the earth: but in reality no branch of the study of external nature is less loaded with technical impediments. The thousands of organic remains which have been cited as witnesses of the ancient character of land and sea, are called by the names which have been assigned them by zoology and botany; the mineralogist has given the titles of rocks and individual minerals; chemists and mechanicians supply the laws of corpuscular actions and movements among the larger masses of matter; and all these parts of knowledge must enter into the consideration of any one who may think himself equal to *propose a general geological theory.* But equal difficulties and not greater facilities belong to the highest paths in every other branch of knowledge; while in the *collecting of facts* for the foundation and confirmation of such a theory, men of ordinary mental power and application can hardly fail to be usefully and most agreeably occupied; nor do they need, for this valuable purpose, to become profoundly versed in any other art or science than that of observation.

At the same time it is to be stated, that observations of most value in every field of human inquiry, have been made by those whose minds, previously directed to the true bearings of the questions in progress, have been ready to perceive and embrace the occasion of adding *new and appropriate* truths to the stock already gathered. It is therefore most important that as much of the *interpretation of geological phenomena* as can be correctly advanced, should be openly and frequently communicated to the public at large; since by this means the mass of ignorance and prejudice, which it is the function of science to remove, will be attacked at all points, and thousands of valuable facts disclosed in railways and canals, in wells, collieries, and mines, will be saved from that oblivion into which all the merely experimental acquirements of practical men too easily and quickly fall.

There is, besides, another class of persons to whom these remarks may be useful. The body of mere travellers who now hurry over the globe on the wings of steam, would be converted into valuable pioneers for the yet unexplored wastes of geology, could they be made to see and feel the power which is possessed by every voyager to contribute, though not so abundantly as the prince of travellers, Humboldt, to the stores of natural science. In meteorology, magnetism, zoology, and botany, as well as geology, the officers of the army and navy have begun to distinguish themselves; and it is with a view to extend this honourable love of knowledge, by showing some of the popular and economical applications of geology, that the following remarks and suggestions are written.

Aspect of the Earth's Surface.

Most unjustly has Natural History been accused of favouring merely minute and curious inquiries into the small parts of creation, and of neglecting the larger views and contemplations which delight the man of taste and refined feeling. Whoever reads the works of Pallas, Humboldt, White, or, to come more nearly to our subject, converses with Sedgwick or examines the pages of Lyell, will acknowledge the error of this misrepresentation. Mr. Murchison in his work now published*, has vindicated geology from this aspersion, and, while exploring with extraordinary zeal and minuteness the recesses of the border of Wales, has stopped to admire the feudal ruins and trace the smiling landscapes of that interesting region. Often has it occurred to ourselves, while traversing other districts not less rich in curious geological truth, to rejoice in the new knowledge and deeper love of nature which an investigation into the ancient *causes* of the present *aspect* of the land and sea had imparted; the puny hammer has dropped from

* The Silurian System, in two volumes 4to.

our hands while contemplating the mighty waste produced by atmospheric variations on rocks which in our monumental buildings have stood the injuries of a thousand years; and we have turned from the perishing granite of Arran, or the bleached and weathered limestones of the Wye or the Meuse, to compare these proofs of partial and slow decay with the deep chasms and wide valleys which now diversify the surface of the land, and to inquire whether the same causes long continued, or other causes operating with greater intensity, have given to the earth this

"Pleasure situate in hill and dale."

The intellectual enjoyment of contrasted scenes, far from being diminished by the application of scientific methods of research into the causes of their differences, is, in fact, very incomplete without such addition; and few persons really do feel gratification in contemplating the beauties of nature, or the miracles of art, who have not learned to associate with the mere perceptions of form and colour, circumstances of higher and deeper interest for the mind.

Outline of Land and Sea.

One of the circumstances most obvious to a geologist, but most unintelligible to an ordinary observer, is the real and necessary dependence of the form and aspect of the earth's surface on the quality and arrangement of the rocky materials beneath. If the reader will place before him a coloured geological map of the British Islands*, he will easily perceive the truth of this statement, by comparing the outline of the coast with the geological structure. There is a remarkable tendency in the English and Scottish coasts to run out into long points and retire into bays in lines more or less directed from south-west to north-east, as the long projections of Cornwall, Cardiganshire, Carnarvonshire, the Isle of

* One recently published by the author of this volume, at a moderate price, may be used for this and other purposes of reference.

Man, Galloway, Isla, the Hebrides, Orkneys, Aberdeenshire, Norfolk, plainly denote. The direction from N.E. to S.W. is the most prevalent one in England, Wales, and Scotland; in Ireland, several directions of strata appear, and the tendency to form promontories and bays is correspondingly varied.

Passing to more precise inquiry, we find that the *position* of the rocks in anticlinal and synclinal axes is a fertile source of local and general irregularity of outline. The Hebrides may be viewed as the tops of one long anticlinal range of gneiss mountains; nearly parallel to these are the loftier chains of the North-western Highlands, from Mull to Caithness, and the broader band of the Grampians, both running out into vast projections; while between these severally, in synclinal lines and newer strata, are a parallel channel of the sea, and a parallel vale which unites the opposite bays of the Moray Frith and Loch Linnhe. Another anticlinal ridge in a north-east and south-west direction forms the Lammermuir and other mountains from St. Abb's Head to the Mull of Galloway, and between these and the Grampians sinks the synclinal axis of the retiring coasts of the Forth and Clyde. In all these cases, the outline of land and sea is obviously the necessary result of the intersection of parallel ridges and hollows by the general sea line.

Farther south we find, on the eastern coast, the influence of *unequal hardness* in the rocks which front the sea. The straight line of the Northumberland coast presents a series of carboniferous rocks which waste slightly and equally; the hollow at the mouth of the Tees is in soft and perishing red sandstones and clays; the prominent points of Whitby Abbey, Scarborough Castle, and Flamborough Head are feebly guarded by oolitic limestones and sandstones, and hard chalk; while the bays of Filey and Bridlington are excavated principally in diluvial clays and sands. Vast areas of clays underlay the wide levels of the Fens of Lincolnshire and Cambridgeshire, which mark the ancient indraught of the North Sea; while the chalk of Norfolk and Kent makes bold projections on each side of the tertiary clays and sands of the Basin of London. Here, however, we have again to notice the influence of the *position* of the strata; for the Thames passes to the sea in a synclinal trough, and thus its deep indentation is readily explained. The Straits of Dover and Boulogne depend for their narrowness on the anticlinal ridge of the Wealden; parallel to this is the anticlinal fault of the Isle of Wight and Purbeck, by which these districts are extended east and west; and between the two runs the Hampshire trough, which is now filled in the deepest parts by the channel of the Solent.

It appears unnecessary to extend these remarks on the outline of the land and sea, since every where the same principles give equally certain explanations both on a large and small scale. We may therefore turn to consider the interior of a country like England.

Undulations of the Interior.

Geographers have noticed, as a fact of frequent occurrence, the prevalence of bold coasts and high land on the western sides of continents and islands, and of sandy shores and low countries on their eastern boundaries. This is true with regard to a large part of the American continent, England, Norway, Hindostan, and other districts; and it may hereafter be found of importance in geological theory. In England, the existing information on the distribution of strata, and lines of subterranean movement, is quite sufficient to give the clue to this peculiarity of structure, and at the same time to explain the exceptions to the general rule.

With the exception of the anticlinal ridges of the Isle of Wight and the Wealden, a swelling under the Yorkshire oolites, and the great *faults* of the valley of the Tyne, no subterranean disturbance of great importance breaks the easy slope of the secondary strata in the eastern parts of England. But on the western boundary of the island, a very different scene appears. Bold anticlinal axes, and other dislocations without number, undulate the stratification of Cornwall and Devon, South and North Wales, the western sides of Derbyshire, Yorkshire, and the almost insulated group of the Cumbrian mountains; and these include the points of greatest elevation, and the ridges of boldest rocks, both inland and on the sea coast, which England has to boast.

Most of the great dislocations here noticed occurred in early geological periods, and besides the local elevations which they have imparted to the western districts of England, they had the effect of entirely changing the bed of the sea, in such a manner as to cause general slopes to the eastward, which were not reversed during the whole subsequent periods of geology. Hence arises another peculiarity in physical geography, which has been long known to inquirers and surveyors, viz. the alternation of ridges and hollows, on lines directed north-eastward and south-westward through a large portion of the secondary as well as primary districts of England.

To describe instances of so well known a truth would be very unnecessary; but we may remark in North Wales the alternation of the Menai Straits, the Snowdonian Chain, the Bala Vale, and the Berwyn Mountains, all ranging north-east and south-west, as very illustrative of the fact and the explanation. In South Wales Mr. Murchison has traced the same connection of anticlinal axes and hilly ground; the great hollow which crosses Devonshire from west to east, is formed in a trough of the strata between the Dartmoor and Exmoor ridges; Mendip is an anticlinal rock ranging east and west; Malvern, a narrow chain passing north and south; Charnwood Forest runs west north-west.

The effect of these various elevations on the ancient strata in the western parts of England, is sensible in the very general declivity to the east or south-east which belongs to the carboniferous, oolitic, and cretaceous strata. And as among these the materials present unequal resistance to the atmospheric agents of destruction, and waste unequally, long chains of limestone hills alternate with wide parallel vales of clay, and render a journey from London to Bath, Worcester, or Newark, a succession of similar vales and hills. One tertiary vale, one cretaceous ridge, one or more vales in clay, alternating with as many ridges of oolite, are crossed on each of these roads in the same order of succession. These parallel vales are frequently, though not always, filled for parts of their length by great rivers, like the Isis or the Thames; and investigation easily shows that the hollows are not the result of fluviatile action, but of some earlier and greater force of nature, which excavated the *wide vale* in which the river now finds a *narrow channel.* There can be little room for doubt that the currents and tides of the sea, in action at the time of the elevation of the land from its ancient level, were the instruments by which the softer strata were worn away, and thus, with a considerable approach to accuracy, we may assert, in general terms, that by direct and indirect effects, the leading features of the earthy surface are distinctly referrible to the force of interior heat.

Scenery.

The charm of rural landscapes, the romantic pleasure of mountain prospects, and sequestered dells and waterfalls, is but feebly appreciated by those who, unacquainted with the principles of art, have not learned to perceive in all the works of nature the operation of law, and to trace in all the diurnal aspect of creation the effect of many preceding revolutions. The greater features of physical geography are explained by subterranean movements and their consequences; the minuter proportions, which are the proper province of pictorial art, are partly due to other circumstances. The richness or desolation of countries, besides the obvious influence of elevation and climate, proximity to the sea, or snowy mountains, is not a little dependent on the chemical quality, and texture of the subjacent rocks, for these, by their decomposition, have furnished, in general, the soil; which does not indeed feed, but is a channel of nutrition for the vegetable world.

Let any one compare, for example, the glorious trees and rich pastures of the vales of Severn and Avon, situated on lias and red marl, with the stunted oaks and poor herbage of a great part of the broad vale of York, which is filled by gravel *drifted upon* the same red marls and lias; or, in the vale of York itself, contrast the finely wooded and fertile region about Thirsk, where these strata come to the day, with the naked plains between North Allerton and the Tees, and he will see the importance of attending to geology in estimating the agricultural condition of a country. Through a great part of England, the various ranges of secondary limestones have characters of outline and surface by which they may be fully represented in a painting. Whoever has admired the Sussex Downs, or Yorkshire Wolds, will seldom fail to recognise, in other situations, those broad, rounded, and gracefully swelling hills melting into gentle hollows, that smooth short herbage, and that pleasing though dry and treeless surface, which belongs to the chalk of most parts of England. Different from these, in many respects, are the tracts of the Gloucestershire and Oxfordshire oolites, with their tabular summits and intervening woody vales of clay, and the older limestones below the coal wear other and bolder aspects, and all are different from the intersecting outlines and rugged surfaces of the primary strata of slate, mica schist, and gneiss.*

But besides these general characters of *district scenery*, it is a familiar truth that every different kind of rock has peculiar forms in the mass, particular arrangements of the structural lines, and even modes of wasting, and vegetable accompaniments, which are often

* See on this subject the remarks which accompany each system of strata in Vol. I.

attended to as pictorial effects, but which furnish to the geologist the further enjoyment which arises from inquiry into the cause. By a knowledge of the divisional structures of rocks*, a geologist can very frequently determine at a distance the nature of a rock, distinguish basalt from slate, limestone from sandstone; and thus his sphere of gratification from scenery is enlarged, his perception of the minuter shades and lights of the landscape become more vivid, and his memory of past combinations more enduring.

It is needless to pursue this subject. Who has ever imagined that the ruins of a rich monastic edifice are less admired by the architect who strives to discover the principles of its construction and the theory of its decoration, or the antiquarian who searches the records of its overthrow, than by those who merely gaze on these masterpieces of the building art, without striving to penetrate the mystery which time and the ravages of man have gathered round the ancient aisles and turrets? Geologists are, as Cuvier felt and said, "antiquaries of a new order," and their enjoyment of the fair scenes of the earth which typify the will of their Creator, partakes of the same high and solemn character which belongs to the intelligent contemplation of the noblest monuments of ancient art.

Economical Applications of Geology.

Agriculture.

Agriculture, which, of all branches of human in dustry, seems most directly dependent on the qualities of soil and substrata, has been hitherto very little benefited by the progress of geological science. Perhaps the expectations of those speculative farmers who desire to turn to good account the discoveries of botanical

* See Vol. I. p. 62,

physiology, vegetable chemistry, and geology, require some better direction to attainable objects, than botanists, chemists, or geologists, are likely to furnish. That plants, by growing frequently on the same spot, poison the soil for themselves, though not for other plants, appears a reasonable generalization of well-known facts: that certain successions of crops are best fitted for particular soils, is incompletely known by experience, and may be turned to a profitable account by the union of botanical and chemical research.

The chemical quality of soils, to judge from a superficial examination, appears to be of real importance. Why else, amidst the heather which covers thousands of acres in the moorlands of the north of England, should there appear not one plant of Dutch clover, though upon the removal of the heath, and the application of quick lime, this plant springs up in abundance? Why else does Cistus helianthemum love the calcareous soil, the oak delight in stiff clay, the birch and larch flourish on barren sand? Yet, to all the conclusions drawn from facts of this nature, exceptions arise, and the *relation of the soil to moisture* appears quite as fertile and general a source of difference of vegetation and productiveness, as any peculiarity of chemical constitution. We once took the pains to notice every species of plant growing on a purely calcareous soil 2000 feet above the sea, on Cam fell in Yorkshire, and among them all, it appeared that not one was commonly supposed peculiar to limestone.

It appears to us that it is chiefly by their various power of conducting moisture from the surface that rocks of different kinds influence the soil above them; and this is a circumstance which is sometimes interesting to the farmer, for another reason. It is not doubtful that in many cases there is a possibility of draining land which is underlaid at some small depth by a jointed calcareous rock, just as by sinking a few feet in a mining country, through clay to limestone, the whole drainage of a mine may often be passed downwards, through the natural channels of the rocks.

One of the most obvious sources of advantage to the farmer from an acquaintance with the distribution of mineral masses, is the facility with which in many instances the injurious effect of small springs coming to the surface may be obviated. The theory of the earth's internal drainage is so simple, that every man of common sense would be able to drain his lands upon sure principles, or else to know precisely why it cannot be drained, if he were to become so much of a geologist, as to learn what rocks existed under his land, at what depth, and in what positions. Springs never issue from stratified masses, except from reservoirs some how produced in jointed rocks — and at the level of the overflow of these subterranean cavities. Faults in the strata very frequently limit these reservoirs, and determine the points of efflux of the water. Let those faults be ascertained, or the edge of the jointed rock be found, the cure of the evil is immediate. But some geological information is needed here ; and landed proprietors, who think it less troublesome to employ an agent than to direct such a simple operation, may at least profit by this hint, and choose an agent who knows something of the rocks he is to drain.

The same knowledge which guides to a right general method of draining, conducts to a clear and almost certain method of finding water by wells, and enables an engineer to predict with much probability, whether, at what depth, in what quantity, and even of what quality, water will be found. Why is water so generally found by deep wells at London and Paris? Why is it often so abundant in these wells? Why is it often of pure quality, though in the descent small quantities of impure water are frequently penetrated? Because under both these capitals, the open, jointed, purely calcareous chalk strata, in great thickness, converge with opposite dips, and collect the water, which, upon the perforation of the superincumbent masses of clay, &c., rises with much force, and continues to flow, unless drained by other of these "Artesian" wells. This method of obtaining water is now commonly known, but deserves to be far more extensively practised in agricultural districts, where natural springs of pure water are rare blessings.

Another thing, probably of importance to agriculturists, is the discovery of substances at small depths which, if brought to the surface, would enrich, by a suitable mixture, the soil of their fields. This is very strongly insisted on by sir H. Davy in his Essays, and considering how easy a thing it is for a landowner to ascertain positively the series of strata in his estate, it is somewhat marvellous that so few cases can be quoted, except that of sir John Johnstone, bart. of Hackness, near Scarborough, in which this easy work has been performed.

Finally, in experiments for the introduction of new systems and modes of management, with respect to cattle and crops, it will be of great consequence to take notice of the qualities of the soil, substrata and water, for these undoubtedly exercise a real and perhaps decisive influence over the result.

Construction of Roads, Railways, Canals, &c.

In planning and executing public works, such as canals, railroads, and common roads, a knowledge of the rocky structure of a country ought to be considered indispensable, and the boring rod is in continual requisition. But the engineer, who is also a geologist, will find it a surer method of research, to trace the systems of strata across miles of country, than to merely feel by the chisel at so many points of a line. To fix the line of a road is the problem, and a knowledge of the geological structure of the country on a large scale is one of the grand data for a true solution of it. When the line is fixed, the practical man will need minuter information than geology can give, but there will be many occasions for the exercise of this science where tunnels, and deep cuttings often show loose sands and other formidable things unexplored by the boring-rod, though not beyond the expectation of a geologist.

The choice of a line of country for canals may often be rightly governed, by attending to the series of strata, and the dislocations to which they are subjected. For thus the summit levels may often be conducted in argillaceous tracts, or in synclinal hollows, where not only no waste of water need be dreaded, but by suitable trials fresh supplies may be had at moderate depths from the surface.

Building Materials.

The assistance which Geology can render to the architect in the choice of building materials is considerable, but not easily defined. Indeed, it is rather because a geologist of experience has necessarily directed his attention to the various degrees of resistance to decay, which rocks of different kinds present, than by any deductions from pure geology, that he can materially aid researches in this respect. There is no doubt that very great benefit would result to the building art, if the whole kingdom were surveyed by geologists and architects, for the purpose of determining generally the occurrence and qualities of stone suited for great and costly edifices. In such a survey it would be proper to inquire how far the indications of durability presented in natural sections were corroborated by the evidence of ancient buildings; and a complete investigation would require further the examination of the chemical quality, mechanical strength, thickness, and other circumstances *of the several beds* of a rock.

The importance of this caution will be evident when we state that Roman sculptures remain at Bath and York, executed in oolite, magnesian limestone, and millstone grit, which yet retain all their characteristic perfection, while other Bath oolite, magnesian limestone, and gritstone have perished in churches and houses in less than 100 years. The reason is, that the different beds of a rock are of very unequal value, and here the geologist or scientific mason will have their claim to attention.

As certain trees will bear the ocean air even in our unfavourable climate and others not, so with stone; it is not equally durable in all situations, but yields variously and unequally to carbonic acid, smoke, dampness, and salt vapours. Most wisely, therefore, has a commission been issued to determine, in the case of the new houses of parliament, the best material for this national work, and we trust that this symptom of reviving attention to the importance of scientific advice in guiding the skill of our workmen, may be the harbinger of a more frequent reference of questions unsuited for the decision of statesmen, to those persons who have, by a life of study, qualified themselves to give opinions useful to their country.

Coal and other Mineral Products.

Two things have been established by geological research in opposition to the contracted "experience" of colliers, and it is difficult to say which is most important. First, it is perfectly ascertained that coal is limited in Europe and America, almost absolutely, to one portion of the series of strata. Secondly, it is demonstrated, that coal occurs in abundance and of excellent quality beneath large tracts of country where few or no indications of its existence appear at the surface. In the practical working of coal which *has been discovered*, geological principles may often be useful in determining its probable extent, but their main value is in the *discovery of coal in new situations, and the arresting of costly and fruitless trials for coal, where it cannot be found.*

In both of these points of view, geology appears in that favourable light when, compared with mere "practical knowledge," that science always occupies when compared to those branches of experience which it includes. A landowner in one of the midland counties, as Northamptonshire or Oxfordshire, where fuel is dear, is naturally anxious to "discover" coal, and being completely ignorant of geology, or blindly credulous in what is called "practical" knowledge, sends for a workman, or "borer," from some coal district, to "find" the coal. A workman from some distant establishment is often preferred, and great alarm is felt lest the opinion of this oracle should be unfairly biassed by the influence of the nearest coal proprietors. Such a workman might be able to give in his own country a right opinion as to the cheapest mode of working a bed of coal, the best mode of walling a pit, and, perhaps, even the proper position for a bore-hole. But when he is carried to the oolites and lias of Northamptonshire and Oxfordshire, he is expected to decide on a question of even national importance, and to influence a landowner, perhaps already impoverished, in the desperate venture of searching for coal at the cost of many thousand pounds, merely because the ditches yield blue clay (which the collier calls "metal") or a bit of jet! At the same time the youth of Oxford and Cambridge receive accurate and admirable instructions from the lips of gifted men; lectures are given in every philosophical institution; geological maps and books are offered in every window; and all these various modes of scientific caution are urged in vain: the pit is sunk, and the landowner is ruined, merely by the *honest error of* a workman set to a task beyond his experience. Is this a harsh picture? Let the recollection of old trials at Bruton in Somerset, and Bagley Wood near Oxford, the more recent folly at Northampton, and the failures of Kirkham and many other localities in the north of England, serve as a warning to inconsiderate persons in other districts. There may not always be found a geologist, willing to turn away from his delightful studies, to avert the ruin which can only fall on those who disregard the plainest truths of geology.

In countries where coal has long been worked, almost every district is explored at least nearly to its boundaries. This is at present the case in England—indeed, generally in Europe; and, consequently, it may be thought that the time has gone by for the geologist to be of service, and the future is to be intrusted to coal viewers and workmen. When coal viewers become geologists, (and this is now very generally the case with men of eminence in that profession), the question of the future extension of our coalfields will be in safe hands; but in all cases, and at all times, this is *a geological question.* Only sixteen years ago, (it is in our own memory,) a valuable estate in Durham was pronounced to be devoid of coal, "because it was situated on the magnesian limestone," and might have been sold under this opinion, but that a geologist of celebrity, Dr. William Smith, showed the falsity of the reasoning, reported favourably of the probability of finding good coal in abundance beneath the property, and advised the proprietor to work it. That estate is now the centre of a rich and well explored mining tract, all situated beneath the magnesian limestone, and this result was the fruit of scientific geology, not "practical" coal-viewing, though the professional mine-agents of the North of England are now employed in extending its benefits.

This fact is one of a large class; and it more particularly deserves attention, because the magnesian limestone overlying the coal of Durham is united in one system of rocks with the red sandstones of Cheshire and Staffordshire, beneath which, as beneath the magnesian limestone of Durham, the coal appears to dip, and the red marls of Somersetshire, under which it is largely worked. Is there a coalfield below the great Cheshire plain?

If this question is to be answered without the boring-rod, none but geologists can venture to speak; nor of these, any but those who have studied the *peculiar* character and relations of the coalfields which border the red sandstone plain in Lancashire, Shropshire, Staffordshire, and Flintshire; or have ascertained the truth in analogous situations, such as the district bordering the coalfields of Leicestershire and Warwickshire.

Perhaps there is a coalfield beneath parts of the Cheshire plain. This may be plausibly argued, from the fact that all the bordering coalfields dip beneath that plain; and the probability of the inference is greatly strengthened by the circumstance (first ascertained by the author of this volume) that the limestone beds which lie in the upper part of the Lancashire coal tract are identical with those previously described by Mr. Murchison from the coalfield of Lebotwood, near Shrewsbury. This limestone is of a peculiar quality, yields peculiar fossils, and lies in connection with coal-beds yielding peculiar plants, at both these distant points; circumstances which go far to prove, not perhaps the entire contiguity of the rock from point to point, but its contemporaneous deposition in one and the same coal basin. It is, therefore, probable that that coal basin is really continuous under parts of the Cheshire plain of red sandstone. Whether it will be worth while to sink for this coal is not a question for geology to answer; but if the attempt is to be made, geological investigation alone can indicate the proper situation for the trial.

Geologists must not be deterred, by the neglect which too frequently has attended their recommendations, from calling on "practical men" to consider and make profitable use of their discoveries and reasonings. Few of their important announcements have really been unproductive; the seed which they have sown, though favoured with little cultivation, has, in the end, grown up to be fruitful of good.

If any one should say geology makes no such prophetic announcements — our collieries are extended without the aid of science, our iron works are supplied with the raw material by the experience of the workmen, and our gold comes by accidental discovery — let him be reminded of the well-known fact that, had geology been believed, the date of the opening of our greatest *northern collieries* would have been earlier by *several years;* let him be assured, that had practical application kept equal pace with geological theory, we should not have been startled, in 1851, by the discovery of immense bands of *ironstone* which were measured and described more than twenty years before; and let it be added, that because geology has of late years made itself heard, even from a distance, and because the principles of this science have been kept in view in the field, *gold* will in future be looked for in the places where it is *likely to be found.* A few words respecting the ironstone and the gold.

The lias shales of the Yorkshire coast are of a greater thickness, and contain a greater variety of valuable substances, than those of the south of England. Besides the jet, cement stone, and alum shale, there are bands of ironstone, sometimes amounting to sixteen feet in thickness, of quality equal to the average of the carbonates of a coal district. They lie toward the upper part of the lias deposits, above a certain series of sandy beds with peculiar and characteristic fossils, and below certain other beds extensively worked for alum. The stone can be obtained at so small a cost, that about 2*s.* 6*d.* a ton is a remunerating price to the adventurer. It is in such immense quantity that an acre will yield from 20,000 to 50,000 tons, and it may be opened in a line of coast and a line of inland cliffs, at many points, and for very many miles of outcrop. Railways are now laid to it, furnaces are built near it, and hundreds of thousands of tons of it are set in motion annually from the hills of Cleveland. This great activity is of sudden growth, one of the wonders of 1851. It was said, what was geology doing, that this vast treasure of iron has been left for the practical man to discover? We reply, this ironstone was measured, its exact geological place marked, and its prominent localities designated, in printed type and coloured sections, more than twenty years previously! *

* Illustrations of the Geology of the Yorkshire Coast (1829.). See

And, in regard to gold, the case is stronger. Constantly brilliant in its natural aspect, occurring in many river beds, easily fusible, remarkably ductile, and exempt from rust, it was known and valued from the earliest ages, and was probably the very first of all metals tried in the fire and moulded by the hammer. Gold has been gathered in every quarter of the globe, in every age known to history and tradition. Scythia and India — the Tagus and the Po — the Hebrus, the Pactolus, and the Ganges — gave their gold to Rome, as they had given to earlier masters. Yet not all this immense experience, sharpened by the "auri sacra fames," produced philosophical views of those co-ordinate phenomena by which the presence of gold could be predicated in new situations. It was simply a matter of trial and error. At last it came under the domain of geology, and was treated as a geological problem. The usual consequence followed — experience became science, and further discoveries were anticipated by theory.

For not only were observations having the character of scientific generalization published many years before the late discoveries, but public attention was distinctly called to their practical application, and a certain country was definitely indicated as likely to be highly productive of gold, and worthy to be explored for that metal. This was done by Sir Roderick Murchison — one who might well be excused, by the variety and importance of his explorations, if he had left wholly to others the care of pointing out the economical application of them.

But, after surveying the Ural, and publishing, in 1844, his critical observations on the old mines of that "hyperborean" district, he took several occasions publicly to declare the general views to which they had conducted him; made a special comparison of the Ural with the eastern chain of Australia (1844); invited the Cornish miners to emigrate to New South Wales and dig for gold on the flanks of the "Australian Cordillera,"

also an earlier description of these ironstones in Young and Bird's Survey (1822).

where gold had been found in small quantity, and in which, from its similarity to the Ural, he anticipated that it would certainly be found in abundance (1846); and presented a note on the subject to the British Colonial Minister (1848).*

Facts like these are unanswerable; but do they not teach us that it is of the utmost importance to connect more closely the theory and the practice, the intellect and the hand; to place the treasures of science within the grasp of experience; to bring together the Murchisons and the Hargraves, the men of thought and the men of action, so that right ideas may become fruitful deeds, and patient labour be encouraged to undertake enterprises which science shows to be of good omen. The lectures which are now in course of delivery on Australian gold at the Museum of Practical Geology, are a step in this direction. A Mining School is established there. If it produce the fruits which are expected from such an institution, many benefits will accrue to humanity; knowledge will be diffused among classes who know how to value it; industry will be better guided and better rewarded; our miners will not breathe the slow poison of mephitic air, nor perish by hundreds through the explosion of inflammable gas.

It appears unnecessary to extend these proofs of the value of geological principles to the agricultural and mercantile interests of a nation. One of the most obviously useful applications of science is in the colonies sent forth by a commercial people; and perhaps no more important service could be rendered to Australia or Canada, than by accurate geological surveys, such as are now proceeding steadily in several of the United States of America.†

This is, however, not the place to advocate plans

* See Trans. Roy. Geog. Soc., xiv. p. xcix. Trans. Roy. Geol. Soc. of Cornwall (1846.), p. 324., and Rep. of Brit. Assoc. 1849.

† This passage is left as it was written some years ago, for the purpose of remarking that the appointments which it suggested are now made — Mr. Logan is surveying Canada, and Mr. Stutchbury is engaged in Australia.

of this nature; nor can it be expected that recommendations for colonial advantage will be much regarded in times when even the laborious surveys of the geology of England have been, till lately, left entirely to the generous self-devotion of individuals. It cannot be expected that costly works, like that on the "Silurian System" and some others we could name, produced at private expense, should be numerous; yet, except on the scale of illustration adopted in these volumes, they are inadequate for their object, and unsatisfactory even to their authors. One step has, however, at length been taken: the Ordnance Survey has been rendered in some degree serviceable to geology, both in England and Ireland; and the officers who conduct this noble work are both able and desirous to make it a geological as well as geographical monument.

Let this truly national labour be completed; let the Mining Districts be illustrated by maps on a larger scale; let a system be introduced by which invaluable mining records, now perishing in the unsafe custody of individuals, shall be preserved for the benefit of this and future times: the public will reap incalculable advantage, and geologists will advance nearer to completeness the bases of their speculations. This is all, or nearly all, the encouragement which Geology needs from a government; or rather, these are the most obvious modes of giving to the community a foretaste of the benefits which this science is destined to bestow. Strong in its fundamental facts, corroborated in its inferences by the progress of all collateral branches of the study of Creation, linked in union with the highest forms of scientific truth, and grasping at objects full of the noblest interest for man, and the most reverential thoughts toward the Maker and Preserver of the Universe, nothing but the general decay of the human intellect will permit Geology to languish, till the Natural History of the ANCIENT EARTH be known to its MODERN occupier MAN.

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THE END.

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